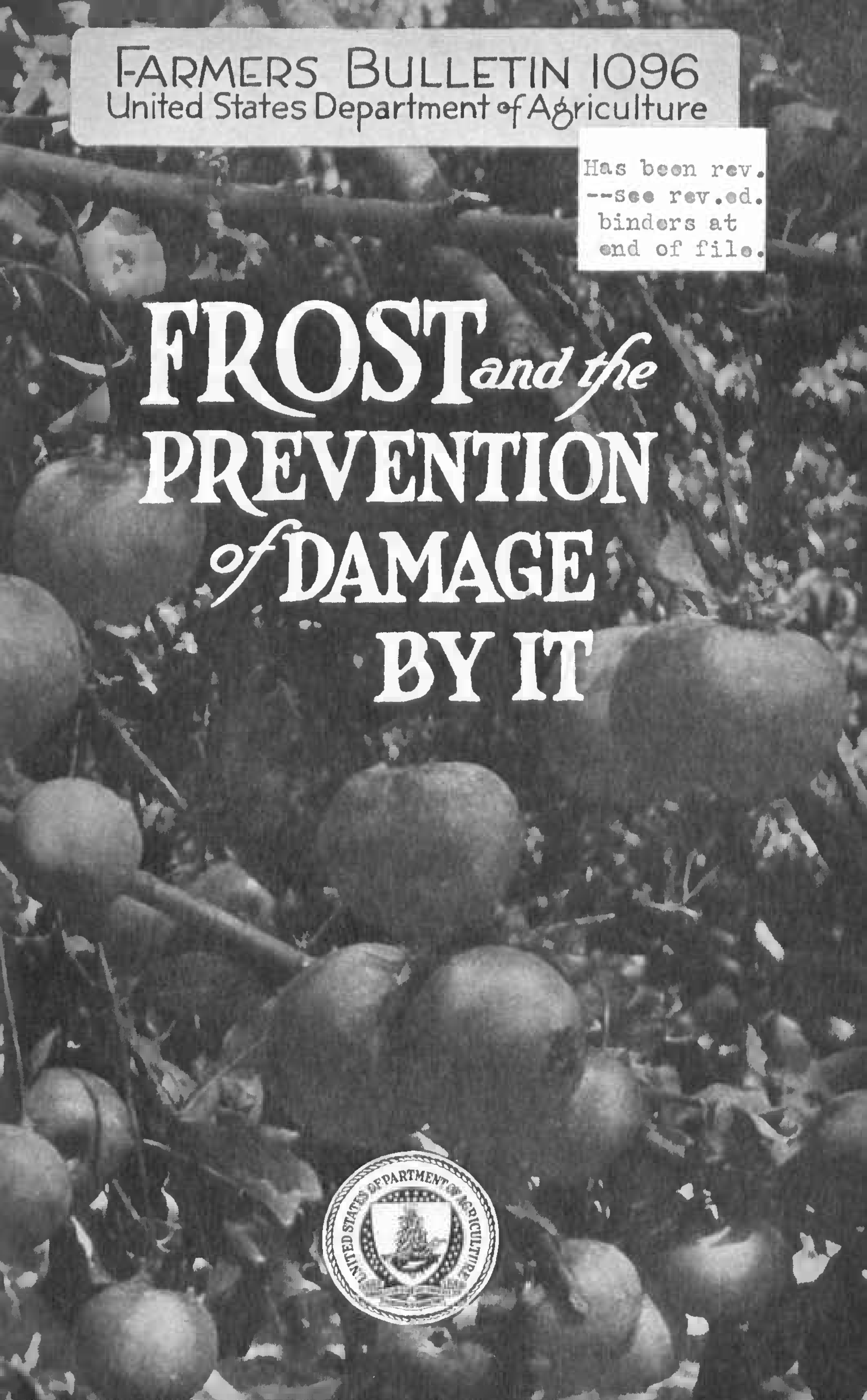
FARMERS BULLETIN 1096
United States Department of Agriculture

FROST and the PREVENTION of DAMAGE BY IT



ALL FROST PROTECTION METHODS, from the simplest to the most complicated, can be carried on more successfully if the processes by which the earth's surface cools at night and the factors which influence the rate of cooling are well understood.

In the first part of this bulletin an attempt has been made to describe in a simple, elementary manner the changes that take place at and near the earth's surface on a frosty night, so that persons protecting plants or trees may be able to understand how their protective devices operate to prevent damage and in what manner they are most efficient. In treating a matter of this kind it is practically impossible to eliminate all technical terms, but so far as possible these have been carefully explained in simple language.

The larger portion is given over to a discussion of the various methods and devices now being used for protection against frost, together with a chapter on temperatures injurious to plants, blossoms, and fruit.

Contribution from the Weather Bureau
C. F. MARVIN, Chief
Washington, D. C. April, 1920

FROST AND THE PREVENTION OF DAMAGE BY IT.

CONTENTS

FROST DEFINED

WHAT IS FROST?

The words "frost" or "hoar frost" are used to designate the deposit of feathery ice crystals which usually form on the ground or other exposed surface whose temperature has fallen to 32° F., the freezing point of water, or lower. In a larger sense, the occurrence of any temperature of 32° F. or lower, whether accompanied by a deposit of ice crystals or not, is called a frost.

Frosts are spoken of as light, heavy, or killing, depending on the degree of damage to growing crops. Since the same temperature that kills young tomato plants may not injure fruit blossoms, a frost that would be called "killing" by one person may be regarded as "light" by another. During the growing season a period of extremely cold weather accompanied by strong winds, when the air for a considerable distance above the earth is chilled, is sometimes called a "freeze." True frosts occur only when the surface air is relatively calm.

In order to understand the underlying principles of frost protection it is necessary to know something of the methods by which the ground surface and lower air cool during the night.

HOW FROST IS FORMED

Whenever two objects or portions of the same object are unequally heated, the colder always gains in temperature at the expense of the warmer, the tendency being to equalize the temperature throughout every portion of the bodies. The interchange of heat is accomplished in two ways, radiation and conduction, each of which will be discussed separately as it bears on the matter of the occurrence of frost.

Radiation.—The heat and light from the sun come to us through space in a form of wave motion called radiation. The atmosphere offers considerable obstruction to the passage of these waves. Even when the sky is very clear, rarely more than 65 per cent of the radiation penetrates to the surface of the earth, the part absorbed being expended in raising the temperature. The region near the upper limits of the atmosphere is one of intense cold. As the sun, having a much higher temperature than the earth, radiates heat to the earth, so from the surface of the earth heat is radiated to the much colder upper limits of the atmosphere.

The radiation of heat from the earth is continuous both day and night when there are no clouds or other obstructions between the earth and the upper atmosphere. During the day the amount of heat received from the sun is so much greater than the amount lost by radiation from the earth that the temperature rises. After the sun sets, however, no heat is received to counterbalance the loss by outgoing radiation and the temperature falls.

Conduction.—Heat may be interchanged between different portions of the same body, or between two separate bodies in actual contact, by conduction. When one end of a bar of iron is held in a fire, the end away from the fire soon becomes too hot to hold in the hand. The heat is transferred from the hot portion of the bar to the cooler portion by conduction. The shortness of the time taken for the heat to reach the cooler end of the bar indicates that iron is a relatively good conductor of heat. On the other hand, one end of a stick of wood can be held in the fire until it is completely consumed without the other end becoming very warm; therefore wood is a poor conductor of heat. Of course, if the stick ceased to burn and the heat in the burning end were not lost, the heat in the warm end would eventually be distributed equally throughout the stick. Both the soil and the air are very poor conductors of heat.

During a clear, calm day the temperature of the ground surface is raised by the heat received by radiation from the sun and the air in immediate contact with the ground becomes warmed by conduction. Since the air is so poor a conductor, the increased temperature of the ground is imparted to only a very thin layer of air at first. How-

ever, as soon as a small portion of this layer becomes warmer than the air above and around it, its density is lessened and it is forced upward and replaced by the cooler and denser air near by or above. This air is also warmed in turn by conduction from the ground and rises to make room for more cool air. The heated air continues to rise until it reaches a point where its temperature is the same as that of the air surrounding it. This process continues until, near sundown, the temperature of the air is highest near the ground and decreases at a more or less uniform rate with increased distance above the ground up to a height of a thousand feet or more.

After the sun goes down the ground cools rapidly through radiation, and its temperature soon falls below that of the layer of air in contact with it. As soon as this occurs the surface air begins to lose heat to the ground by conduction. The air near the ground now becomes cooler than the air above and its density becomes increasingly greater. Instead of rising, as did the surface air during the day, its increased density tends to keep it in contact with the ground. Thus over a level plain on a clear, calm night we find a relatively thin layer of cold air near the ground with an increase in temperature up to an altitude of between 300 and 800 feet.

Air Drainage.—Over gently sloping ground the force of gravity tends to cause this thin surface layer of cold air to move down the slope and to gather in depressions in somewhat the same manner as water. The similarity between the flow of water and of air down a slope is inexact, however, because of the difference between the physical characteristics of air and water. Water is a practically incompressible liquid; therefore neither its volume nor its density is much affected by a change in pressure. Air is a compressible gas and its physical condition is influenced greatly by such a change. The atmosphere exerts a pressure at sea level of about 15 pounds to the square inch. Because of its compressibility, the density of the air decreases rapidly with increase in altitude. In accordance with a law governing the behavior of gases, a decrease in density is accompanied by a decrease in temperature and an increase in density causes an increase in temperature. When air moves downward along a gentle slope or a steep hillside, its altitude is constantly decreasing and its pressure and density are constantly increasing. The increase in density causes an increase in temperature (heating by compression) at the rate of about 1.6° F. for every 300 feet decrease in elevation and an increase in elevation causes a decrease in temperature (cooling by expansion) at the same rate, provided there has been no loss or gain of heat from other sources.

Over a gently sloping plain or valley floor it is possible for the cold surface air to drain down the slope in much the same manner

as water, as the vertical movement of the air takes place so slowly that the heating effect due to decrease in altitude is more than offset by the cooling due to contact with the ground which has been cooled by radiation. When we are dealing with a steep hillside, however, movements of the surface air are more complex and have little similarity to the flow of water down the same slope.

Like the more nearly level lower ground, the slopes and summits of hills and ridges lose their heat rapidly after sundown through radiation, and their temperature falls. The air in immediate contact with them also cools through conduction so that it is soon cooler

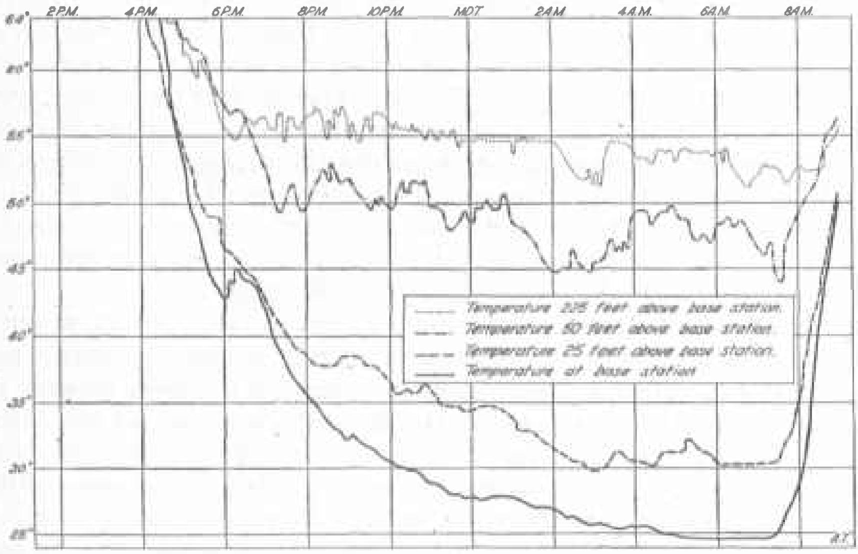


FIG. 1.—Continuous records of the temperature from 4 p. m. to 9 a. m. at the base and at different heights above the base of a steep hillside, showing the great differences in temperature that sometimes develop on a clear, still night. Although the temperature at the base was low enough to cause considerable damage to fruit, the lowest temperature 225 feet above on the slope was only 51°. Note that the duration of the lowest temperature was much shorter on the hillside than at the base.

than the air at some distance out over the valley, but at the same elevation.

If this cooler air in contact with the hillside begins to flow downward directly along the surface of the ground, its altitude will be decreasing more or less rapidly, according to the steepness of the slope, and its density will be increasing. If no further cooling takes place, it will be surrounded by air increasingly colder as it nears the valley floor, while its own temperature tends to increase because of the compression it suffers. As soon as a position is reached where it is warmer than the air surrounding it, its downward movement will be checked and it will tend to rise again until its temperature is the same as that of the air surrounding it. (See fig. 1.)

The drainage of cold air down a valley floor is usually interfered with considerably by outside influences. As soon as the flow begins there is more or less mixing of the cold lower air with the warmer upper air and inequalities in barometric pressure over whole regions may temporarily prevent the flow or even reverse its direction for short periods. Local winds of slight velocity and covering a very limited area often cause a mixing of the air that causes the surface temperature to rise suddenly from 5° to 10°. It is not often possible to know in advance that the drift of the air on a valley floor will continue from one direction during a cold night, though there may be one particular direction from which it very seldom comes.

Effect of Water Vapor on Rate of Cooling.—Water vapor is the most effective of the various gases present in the atmosphere in obstructing radiation of heat from the earth. Therefore, the amount of water vapor present in the atmosphere above a given locality has considerable influence on the rate of fall in temperature at that place during the night; the temperature falls more slowly when the humidity is high than when it is low, other conditions being the same.

The amount of invisible water vapor in the atmosphere varies greatly at different times. At a given temperature only a certain maximum amount can be present. If, when the maximum amount is present, the temperature is lowered, a certain portion of the water vapor is changed to liquid or frozen water, as the amount of water vapor which can be present in the air is greater when its temperature is high than when it is low. No matter how dry the air under natural conditions may be, if its temperature be lowered sufficiently, a point will be reached where the invisible vapor will begin to appear in a liquid or frozen form. The temperature at which this condensation begins is called the dew-point. The drops of moisture which appear on the outside of a pitcher of ice water on a warm day are formed through the chilling of the air in contact with the pitcher. These droplets begin to appear on the pitcher as soon as its temperature has reached the dew point.

The actual amount of water vapor in the air expressed in terms of weight per given volume of air, is called absolute humidity. With a given dew point the absolute humidity is always the same; therefore to determine the absolute humidity it is only necessary to find out what is the temperature of the dew point.

As a general rule the temperature of exposed objects falls more or less steadily after sunset until it reaches the dew point, at which time the invisible water vapor in the atmosphere begins to be deposited on them. If the dew point is above 32° F., the freezing point of water, dew is formed; if it is 32° F. or lower, frost forms. Since dew or frost does not begin to form until the temperature of the ground or other object reaches the dew point, it is ap-

parent that if the dew point is very low, the temperature may fall low enough to cause considerable damage without the formation of any frost. For example, if the dew point is 18° F. and the lowest temperature reached during the night is 24° F., there will be considerable damage to growing crops without any frost whatever. This phenomenon, often called a "black frost," is of rare occurrence in most localities.

Another factor that has great influence on the amount of fall in temperature during the night is the liberation of latent heat in the formation of dew and frost. A definite amount of heat is required to raise the temperature of a given amount of water to the boiling point without vaporizing any of it. After the boiling point is reached, another definite amount of heat is required to convert this water into water vapor, the temperature of the water remaining unchanged during the vaporizing process. This latent heat, stored up in the water vapor, is released whenever the water vapor is again changed to a liquid state. A portion of the sun's heat during the day is expended in evaporating moisture from the ground and from the leaves of plants. When the dew point is reached at night and vapor is condensed, its latent heat is given up. The amount of heat given up on a particular night depends on the amount of moisture precipitated. Obviously, the greater the amount of moisture in the atmosphere, the more will be condensed, provided the temperature falls below the dew point. When the dew point is high, the latent heat given off in the formation of dew is often sufficient to check the fall in temperature almost entirely. Generally speaking, therefore, other conditions being equal, the higher the dew point in the evening the less danger there is of the occurrence of a damaging frost.

WHEN TO EXPECT FROST

The weather in the latitude of the United States is controlled by atmospheric disturbances of great size and varying intensity, which follow one another across the country, moving from west to east. These disturbances are of two types, one of which is marked by low barometer, overcast skies, and rain or snow; the other by high barometer and clear skies.

The main factor in the occurrence of frost is radiation of heat from the earth. When heavy lower clouds cover the sky, they act as a blanket and prevent radiation to the upper limits of the atmosphere, making impossible the occurrence of a true frost. A moderate wind is also generally effective in preventing frost. The formation of a thin layer of cold air near the ground is prevented on a windy night by the mixing of the surface air with the warmer air above.

The important requirements for the occurrence of frost, a clear sky and little wind, are present during the passage of an area of high barometer. As the first-mentioned type of disturbance, the area of low barometer with overcast skies and rain, nearly always precedes the area of high barometer, the saying in many sections of the country, "Three days rain and then a frost," has some basis.

During the passage of a well-defined area of low barometer the radiation from the sun is more or less completely cut off by heavy clouds and the ground is not warmed much during the day. If rain has fallen, the evaporation from the wet ground uses up a great deal of heat and this also tends to keep the temperature low during the day. Therefore, on the first clear night after a rain during the frost season the temperature at sunset is likely to be within 15° or 20° of the freezing point and not much cooling by radiation is necessary to form frost, although frost is not expected in many cases on the first night on account of wind conditions.

Though the moisture in the ground after a rain tends to prevent warming of the ground during the day, it also tends to prevent a large fall in temperature during the night. The water vapor taken up by the atmosphere from the wet ground diminishes radiation. When the dew point is reached the latent heat given up checks the rate of cooling still more, and when the freezing point is reached the conversion of the ground moisture into ice also liberates heat and aids in preventing a further fall in temperature.

Before the second night after the rain the surface of the ground has usually dried out considerably. The dew point is likely to be lower and a more damaging frost is likely to occur at that time. Before the third night the day temperature has usually risen high enough to make unlikely the occurrence of a heavy frost on the Pacific coast, while in the central and eastern part of the United States frost may occur as late as the fourth night if the high pressure area is well defined and moves slowly.

Large bodies of water exert a modifying influence on the climate of localities to the leeward and such localities do not often suffer much damage from frost. A light wind blowing from a large body of water is generally more or less laden with water vapor, which cuts down the rate of radiation; and as the temperature of the water is usually considerably above freezing, the temperature of the air passing from it to the land is high enough to prevent the formation of frost.

Rivers often give up a large amount of moisture to the surface air so that when the temperature falls to the dew point a fog forms which covers a part or all of the lower land in the valley, cutting off radiation and preventing a further fall in temperature.

In valleys near the ocean, fog sometimes drifts in from the water toward morning and prevents a damaging frost. On nights with fog the hillsides are practically always colder than the lowlands unless the fog extends high enough to cover both hillsides and valley floor.

INFLUENCE OF SOIL AND VEGETATION ON MINIMUM TEMPERATURE

In experiments carried on in the cranberry bogs of Wisconsin, Prof. H. J. Cox found differences of from 5° to 10° F. between minimum temperatures registered on the surface of level ground at two points within 6 feet of each other. The ground at the warmer station was bare, while that at the colder station was covered with

Fig. 2.—Average dates of last killing frost in spring.

spaghnum moss. The soil at both points was peat. At a height of 3 feet above the ground this difference in temperature disappeared.

Prof. Cox attributes this difference in temperature to unequal warming of the bare and moss-covered soil during the day and unequal conduction of heat to the surface from below during the night. The soil at the cooler station was shaded by the moss and a large part of the heat received during the day was expended in evaporating water from the plants, while at the warmer station the sun shone directly on the soil, warming it to a greater depth. At night the heat absorbed during the day was slowly conducted to the surface of the bare ground while most of the smaller amount of heat absorbed by the moss-covered ground was prevented from reaching the thermometer because of the intervening moss, which is a poor conductor of heat.

It was also found that the temperature often fell several degrees lower at night over wet ground than over dry ground, because of the heat expended in evaporating moisture from the wet ground during the day. By covering the bogs with coarse sand, the moisture is prevented from rising to the surface from below, and cooling by evaporation is checked. By keeping the bog free from weeds, draining, and sanding, damage by frost may be greatly lessened.

PROTECTION FROM FROST

Since a crop which represents the results of the labor and care of an entire season may be destroyed by frost in a single night, various methods of protection against frost have been practiced for centuries in different parts of the world.

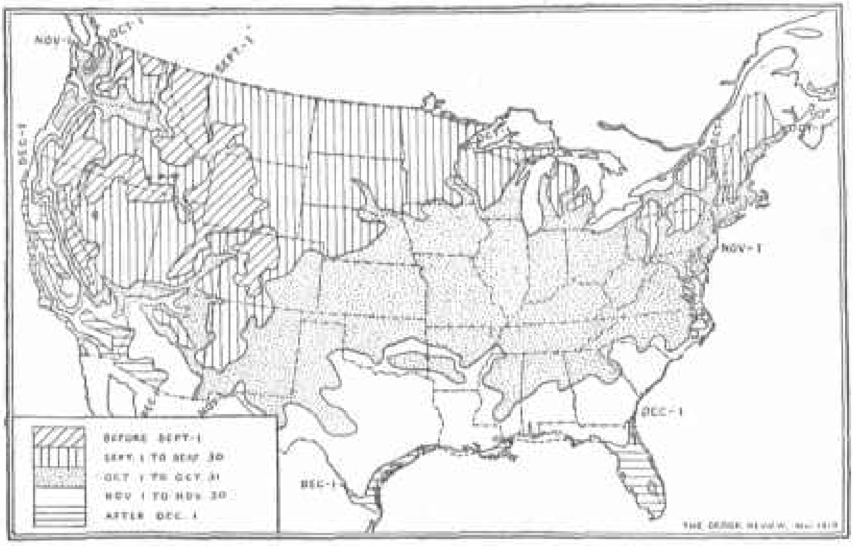


FIG. 3.—Average dates of first killing frost in fall.

The three general principles used in frost protection devices in the United States are:

(1) Conserving heat, (2) Mixing or stirring the air, and (3) Adding heat.

CONSERVING HEAT

The most important method by which the ground cools during the night is radiation. If it is possible to prevent radiation or reduce it sufficiently, the ground heat will be conserved and there will be no damage. This may be partially accomplished by covering the ground or plants with various materials.

Covering with Glass.—Glass is one of the best materials known for screening plants and preventing frost damage, since it is almost

impervious to the waves of outgoing radiant heat from the earth, but allows the incoming heat from the sun to pass through it freely. The expense of covering with glass is too great to allow of its use except for the more expensive plants and flowers.

Cloth Screens.—Experiments have been carried on in California and elsewhere to determine the value of a covering of cloth over orchards and over individual trees. When an acre or more of orchard is thus covered, the minimum temperature may be from 2° to 4° higher inside the covered area than outside, if there is little air movement. In experiments carried on in cooperation by the Weather Bureau and the Southern Oregon Experiment Station of the Oregon Agricultural College, it was found that cloth coverings over small areas of orchard or over individual trees do not have an appreciable effect on the temperature, even when the coverings are of heavy cloth or canvas. This is due to the fact that the cloth does not prevent an interchange between the air under the covering and that outside.

Coverings of rather heavy cloth laid directly over garden truck or other low-growing plants are effective in protecting against moderate frosts. In this case radiation from the ground and plants is almost completely cut off and the air movement is so slight near the ground there is little tendency for the cold outside air to be forced under or through the covering. The temperature of the surface of the cloth exposed to the sky is lowered by radiation and may fall to a low point, but as both the cloth itself and the air underneath the cloth are very poor conductors of heat, the temperature of the covered plants falls much more slowly. The heat which has penetrated a few inches into the ground during the day is slowly conducted to the surface during the night and aids in keeping the temperature under the cover above the freezing point.

It is evident from the above that coverings of this kind should be placed early in the evening when a frost is expected, before much of the heat accumulated in the soil during the day has been lost. Tin cans or other metal coverings should not be used to protect plants from frost damage. Metals are good radiators and conductors of heat and the temperature is likely to fall nearly as low under a covering of this kind as in the outside air.

Lath Screens.—Screens made of laths fastened together with wire (the spaces between them being about the width of the laths) have been used in Florida and California to protect orchards. These screens serve not only to diminish outgoing radiation during the night but also as a shade from the sun. About three-fourths of the sky is screened by a covering of this kind. By placing the laths in north and south directions the direct rays of the morning sun are

completely cut off, which permits of a slow thawing of blossoms and fruit after a heavy frost. This reduces the amount of injury.

Orchard heaters burned under screens of lath or cloth are more effective in raising the temperature than is the case when they are burned in an uncovered orchard.

Other Methods.—Paper covers may be used to protect small individual plants or large paper strips may be used to protect gardens against light frosts. Generally speaking, paper coverings do not afford as much protection as those made of cloth.

Young potatoes and garden truck are sometimes protected by plowing a furrow between the rows and covering the plants with soil.

Cranberry growers in the marshes of Massachusetts, New Jersey, and Wisconsin flood the marshes with water from large reservoirs when frost is expected. For protection against a light frost it is generally sufficient to raise the level of the water in the ditches. For a moderate frost the water level is raised to the surface of the bog and when a heavy frost is expected the vines themselves are covered with water. In the first two instances protection is afforded by the heat given off by the relatively warm water.

Devices for Adding Moisture to the Air.—Smudge fires of damp straw or manure have been used to create a blanket over the area to be protected, the object being to decrease the radiation from the ground rather than to add heat to the air. It is possible that such a method may be successful when the air is calm and is already nearly saturated with moisture. However, heavy frosts generally occur when the humidity is fairly low and a perfectly calm surface air is seldom met with on cold nights; there is usually at least a slow movement down gently sloping valleys or plains. In a relatively dry atmosphere any moisture thrown off by damp smudge fires will be rapidly lost by circulation and diffusion into the great quantities of air above and surrounding it, and the effect in diminishing the rate of radiation will be very small. At the same time, if an effective blanket of moisture could be spread over the orchard, a slight breeze would carry it steadily away, replacing it with cold outside air that has been chilled through contact with soil from which radiation had gone on unchecked.

Spraying of trees to afford protection from frost has been attended with some success. However, it is not possible to combat a heavy frost in this way on account of the heavy coating of ice formed, which strips leaves and even large branches from the trees. If the tree is in bloom the water is likely to cause damage by interfering with pollination. These objections do not have so much weight in the case of protection of garden plants, and spraying with water may be very effective where these are concerned.

Good results have been obtained by turning fairly warm irrigation water into fields or orchards on moderately cold nights. This method will not afford protection against damage by heavy frosts. Frequent irrigation of citrus trees during the winter months may start new growth and render the trees much less resistant to cold.

STIRRING THE AIR

The temperature of the air 40 feet above the ground is often from 7° to 10° higher than that 1 foot from the ground. It is obvious that if the air within this distance from the ground could be mixed, a damaging frost would not be likely to occur in most cases. Attempts have been made to do this with large power-driven fans, but it was found that the expense was far too great for the plan to be considered from a practical standpoint.

ADDING HEAT

The third principle of frost protection is concerned with the addition of heat to the lower air to replace that which is lost by radiation and conduction. This is generally accomplished by lighting a large number of small fires throughout the area to be protected. Oil, wood, coal, oil-soaked shavings, tree prunings, and carbon briquets, or a combination of two or more of these fuels is used.

Persons unfamiliar with temperature conditions in the lower air on frosty nights sometimes speak of the fallacy of attempting to "warm up all out-of-doors." It is well known that warm air is less dense and therefore lighter than cold air. This fact is exemplified in many ways in everyday life; the hot gases from a stove or furnace rising through a flue and the lifting power of the old hot-air balloons are good illustrations. As a matter of fact, roughly speaking, the warmed air continues to rise and cool until it reaches a point where it has the same temperature as the air surrounding it. On first thought it might be supposed that the air warmed by fires in orchards or fields would pass upward to a considerable altitude and be replaced by cold air from outside the heated area so rapidly that the effect on the air temperature in the heated area would be very slight.

However, the factor of temperature inversion on frosty nights (the relatively thin layer of cold air near the ground with warmer air overlying it) completely alters the situation, in that the heated air does not rise far before it finds itself surrounded by air of the same temperature as itself. As the hot gases leave the fires, they mix rapidly with the surrounding colder air, so that the resulting temperature of the whole mass is not very high. When the air 40 feet above the ground is 10° warmer than that a foot from the ground, the heat from the fires is nearly all expended in raising the tempera-

ture of the air within this 40-foot layer. In other words, the warmer upper air acts as a roof which stops the ascent of the heated air. (See fig. 4.)

It is plain that the degree of temperature inversion near the ground, that is, the rate at which the temperature increases with increase in altitude, determines the thickness of the layer of air that must be warmed to obtain a definite increase in temperature at the ground. If the inversion is strong the surface temperature can be raised several degrees more than when the inversion is slight, the amount of fuel consumed being the same in both instances.

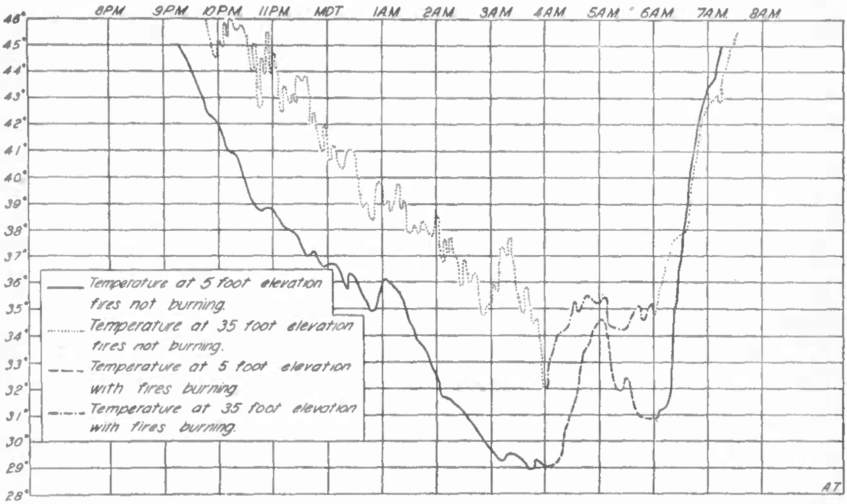


FIG. 4.—Continuous records of the temperature 5 feet and 35 feet above ground on a tower in a pear orchard. Note the large difference in temperature at the two levels before the orchard heaters were lighted at 4 a. m. By 5 a. m. the temperature was practically the same at the two levels, showing that the heat from the burning oil had been nearly all expended in raising the temperature of the air within 35 feet of the ground. This point is further illustrated by the fact that at 5 a. m. when most of the heaters were extinguished, the temperature at the 5-foot level fell rapidly, while it remained practically stationary at the 35-foot level.

The amount of this temperature inversion varies greatly from night to night, and in different localities. It is mainly determined by the amount of fall in temperature from afternoon to early morning. If the afternoon temperature is high and the temperature falls to freezing on the following morning the inversion in temperature is likely to be great.

A large number of small fires will be found to be more efficient in raising the temperature than a small number of large fires, especially in localities where the temperature inversion is relatively slight. The heated gases leave the large fires at a high temperature and tend to rise some distance above the ground, while the gases from a number of small fires are mixed with the surrounding cooler air until the

temperature of the whole mass of surface air is raised slightly, although remaining still relatively low.

Another and probably the most important factor in protection by heating is the amount of air movement near the ground. When the air is calm the air warmed by the heaters remains over the fired area and the maximum results in raising the surface temperature are obtained. When the air is in motion, even though it is moving only a few miles per hour, the heat is steadily carried away and a greater quantity of fuel must be consumed to obtain the same effect on the surface temperature.

The matter of reinforcing the borders of an orchard with one or two extra rows of heaters is of the greatest importance. When the air is in motion, if there is no border row of fires, the heat from the first two or three rows of heaters on the windward side is carried into the orchard, leaving the outside rows practically unprotected. In such cases the temperature in the outside rows may show a rise of only 1° or 2° due to the firing, while the remainder of the orchard may be benefitted by a 5° or 6° rise. To secure the maximum amount of protection for border trees, a row of heaters, 10 feet apart, should be placed about 40 feet to the windward of the outside row, with a similar row about 20 feet to the windward.

The smoke cover has very little influence on the loss of heat by radiation and the effect of smudge fires of damp straw or manure on the temperature is practically negligible. However, a smoke screen is of some value in shading the fruit and blossoms from the morning sun and preventing a too rapid thawing.

Smudging and Pollination.—In some deciduous fruit districts it has been asserted that the smoke from the open oil heaters interferes with pollination. However, the experience of a large number of fruit growers, who for many years have smudged their trees while in full bloom, does not bear out this contention. Pollination usually takes place on the day the blossom opens and even if considerable soot is deposited within the flower on the following night, no damage results. As a matter of fact there is seldom enough soot deposited in a blossom to hinder pollination, even when firing is continued for several hours.

During the seasons of 1917 and 1918 Mr. B. B. Lowry, of Medford, Oreg., cooperating with the county pathologist, smudged six pear trees, including practically all varieties grown commercially in the district, every night from the time the buds began to open until the fruit had set, in order to note the effect on pollination. Three open lard-pail heaters were placed almost directly under each tree and the blossoms were coated with soot to an extent that would never be found in actual practice. The experiment was carefully checked by the writer during the 1917 season. All the smudged trees bore

heavy crops both years and the yield of near-by trees that were not smudged was not noticeably larger. (See figure 5.)

FIG. 5.—Fine crop of perfectly shaped Bartlett pears on tree used in experiments to determine the effect of smudging on pollination. This tree was smudged heavily every night from the time the buds began to open until the fruit had set. Photograph taken soon after spraying.

Statements that bees will not work in blossoms that have been smudged may be due to a lack of understanding of the habits of the

bee. It is well known that bees will often not work on even moderately cool days; if the afternoon temperature is below a certain point, namely about 60° F, the bees may remain in the hive. On days following the occurrence of a frost heavy enough to make smudge protection necessary the temperature is likely to be sufficiently low to keep the bees from working to any great extent. On warm sunshiny days following heavy frosts, however, the writer has often observed great numbers of bees working in blossoms that had been heavily smudged on the previous night.

The smoke from the open heaters is very dense and in some localities the residents of towns have objected to orchard heating on account of the resulting dirt. The smoke problem has been partially solved by the development of improved heaters, but no practical heater has yet been devised that will burn under orchard conditions without giving off some smoke. The newer types are rather complicated and are too expensive to be used for the protection of crops that do not bring a large return. There are few commercial fruit districts in the country that do not suffer severely from frost damage at intervals, and in most localities people are willing to put up with some inconvenience from smoke on a few nights a year in order to avoid the business depression likely to follow the loss of a large portion of the crop.

Protection of Olives.—In some parts of California the olive crop is often damaged severely by fall frosts when the fruit is being picked. In some olive-growing communities as much as 70 per cent of the crop has been lost in some seasons in this manner. Many growers have hesitated to resort to orchard heating to save the crop for fear that the oil smoke would affect the flavor of the olives. Mr. F. Mier, of Fair Oaks, Calif., has been protecting his olives with open oil heaters for several years and has never been able to note any effect on the flavor of the fruit. Practically his entire crop has been packed ripe and has always been of the highest quality. It is unlikely that the oil flavor ever penetrates the thick, tough skin of the olive, but even if this were possible, the treatment with lye which the fruit is given to remove the bitter element would undoubtedly remove it.

Relative Value of Different Fuels.—The kind of fuel most suitable for use in a given locality depends on a number of factors. The first consideration is the relative cost of the different fuels. On the Pacific coast oil is used almost exclusively on account of its low cost as compared with coal or wood. In most other parts of the country coal is the cheaper fuel. The acreage protected by wood fires is relatively small. Because of the ease with which it may be lighted and extinguished, handled and stored, oil is to be preferred when its cost compares favorably with that of other fuels.

Fuel oil of from 25 to 28 gravity is the most satisfactory for use in either the lard-pail or improved type of heater. This oil leaves very little residue and burns practically as long as heavier oils.

Types of Oil Heaters.—Up to the present time few deciduous fruit crops have been valuable enough to warrant the use of any but the simplest and cheapest types of heaters for protection against frost. Since good results can be obtained with these heaters (the lard-pail type) when a sufficient number to the acre is used, the only incentive to change to a more complicated type of heater is the abatement of the smoke and soot. The indications are that the smudge does not injure deciduous blossoms or fruit to any measurable degree and its elimination is desirable only on account of the resulting dirt.

The small open lard-pail heaters are not well suited for the protection of citrus fruits because (1) at the time protection is necessary the fruit is almost ready to be picked and even a small deposit of soot is likely to impair its marketing qualities, and (2) protection is necessary in midwinter, when the temperature is likely to remain below the danger point continuously for 10 or 12 hours and heaters of large capacity and long burning time are required.

A 5-quart lard-pail heater will burn about 2½ hours, but as the oil gets low the amount of heat given off is greatly decreased. The 2-gallon lard-pail heater will burn about 4 hours, but little heat is given off after 3½ hours.

The length of time the larger heaters will burn depends altogether on the amount the drafts are open. To combat the long cold periods, that sometimes visit the citrus districts, without refilling during the night, heaters of a capacity of about 7 gallons should be used. These will burn from 8 to 10 hours at near their full rate.

More than a score of more complicated heaters have been developed with the idea of improving combustion and reducing the amount of smoke. These run all the way from the 3 or 4-gallon capacity short-stack heater (fig. 6) to the high-stack heater of from 7 to 20 gallons capacity (fig. 7). The stacks on the smaller heaters are from 4 to 10 inches high, while on the larger heaters they are from 3 to 5 feet high. With one or two exceptions the "down draft" principle is used in all the improved types. Air is admitted through the top of the oil reservoir, causing the oil to burn there and raise the temperature sufficiently to change some of the oil to gas. The gas then passes upward and is burned as it rises through the stack. A supply of air to support combustion is admitted through holes cut in the base of the stack.

In order to burn clean and supply the desired amount of heat the gas must be given some time to burn before its temperature is

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reduced by mixing with the cold outside air. This is the function of the tall stack. Generally speaking, the high-stack heaters burn with less smoke and soot than any other type in general use. The short-stack heaters throw off less smoke than the lard-pail type, but the amount is large enough to be objectionable.

The high-stack type of heater is open to the objections that the heat is released too far above the ground, at too high a temperature and with too great an upward velocity to obtain the best results. These objections would probably be serious in localities where the temperature inversion is slight, but in southern California, where these heaters are in most general use, the temperature is often 20° higher on a cold night at a height of 200 feet above the ground than at the ground.

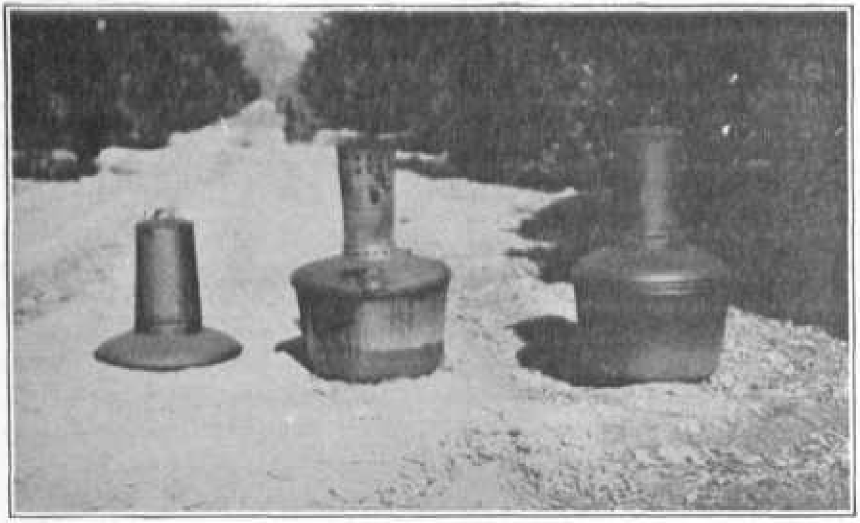


FIG. 6.—Short-stack oil heaters in orange grove. The one on the left has cover removed and draft open. This type of heater has given great satisfaction where there is not too much objection to the formation of heavy smoke.

There is no doubt the heat should be liberated as near the ground as possible in order to obtain the best results. However, at the present time the use of the high stack is the only practicable means of obtaining fairly perfect combustion. Some of the heat from these heaters is undoubtedly lost through its rising too high above the ground, but this is probably nearly offset by the additional heat obtained through the more complete combustion. The smoke and soot given off by other types of heaters are more or less completely consumed in the high-stack heater. It is estimated that from 40 to 50 per cent of the heat in the oil is made available in the lard-pail type, as against 70 to 80 per cent in the high-stack type.

The plan of using small oil heaters which burn slowly and setting them directly under the trees has not met with much success up to the present time. There is always danger of severely injuring the tree if the heater burns too high, and the problem of distributing the heat uniformly throughout the tree has not yet been solved.

Protection by Direct Radiation From Heaters.—Though protection from frost is afforded mainly through raising the temperature of the air by mixing with the hot gases from the heaters, direct

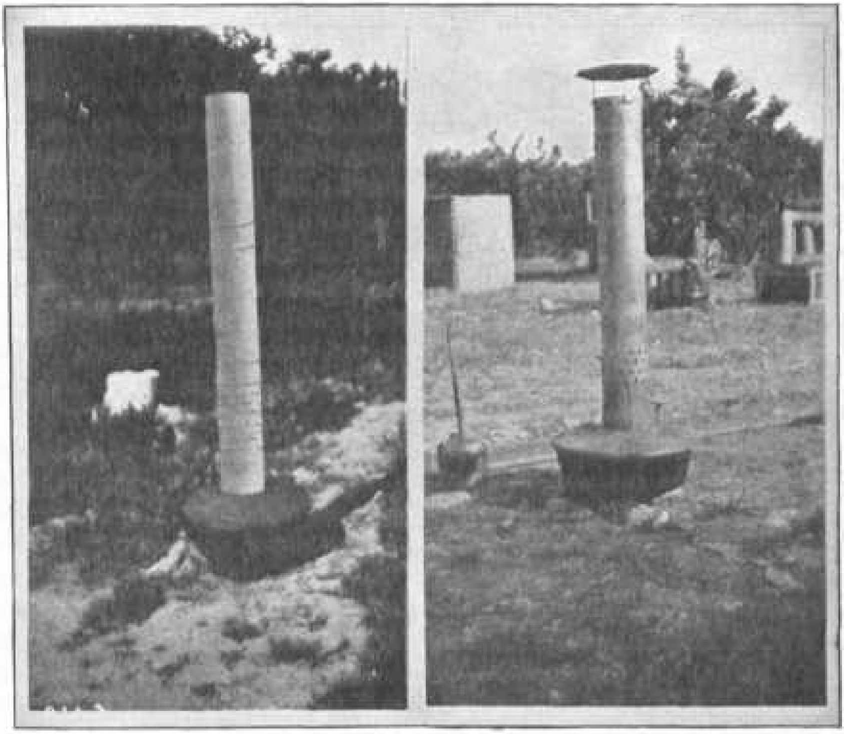


Fig. 7.—Two types of high-stack oil heaters. Air is admitted through a draft opening in the cover of the bowl, supporting combustion at the surface of the oil. The hot gases then burn while rising through the stack, the necessary air being admitted through the perforations near the base. At the left of the heater on the right is shown a lighting torch of the type in most general use. It consists of an ordinary oil can with a long spout, into the end of which is inserted a wick of asbestos wrapped in small mesh wire screen. The lighting fluid is ignited while flowing through and around the wick and falls in flaming drops.

radiation of heat to the plants or trees is important in some cases. This is particularly true when the high-stack heaters are used. When these are burned at a moderate rate at least a portion of the stack is likely to be heated to redness. The heat radiated from the stack to the fruit and foliage serves to counterbalance the loss of heat through outgoing radiation. The amount of radiant heat reaching the tree

depends on the distance from the heater. With increasing distance the radiation intercepted decreases very rapidly.

Experiments conducted by Prof. H. H. Kimball show that when the high-stack heater is burning at a moderate rate with only the lower section of stack red-hot, the heat radiated directly to the tree is sufficient to counterbalance outgoing radiation at a distance of 10 feet. When the entire stack is red-hot the outgoing radiation will be counterbalanced at a distance of about 15 feet.

With the short stack and lard-pail heaters radiation is not of so much importance unless the plants to be protected are very near the heater.

A large percentage of the radiant heat given off by an orchard heater is lost directly to the sky without appreciable effect on the temperature of the air or of the plants. As radiant heat travels in straight lines and is completely absorbed or reflected by fruit and leaves, any fruit shaded from the heaters by leaves or branches can receive practically no direct benefit from the radiated heat. It is plain, therefore, that to obtain the greatest amount of protection from the same amount of fuel, heaters which are most efficient in raising the temperature of the air should be used if possible, rather than those which radiate most of their heat and are not so effective in raising the temperature of the air.

Distribution of Heaters.—For the best distribution of the heat throughout the orchard it is better to have the heaters placed in every row, if possible, instead of concentrating them in every fourth or fifth row. This makes for a more general intermixing of the warmed air from the heaters with the cold air surrounding them. If rows of heaters some distance apart are lighted through an orchard on a calm morning, from the edge of the fired area it is possible to note "arches" in the smoke over the fired rows, with depressions in between. If the air is moving steadily from one direction, even slowly, the heat will be spread out and mixed so that this "chimney" effect will not occur, even if rows some distance apart are lighted.

In some parts of southern California, where the air drift is practically always continuous from the same direction during a cold night, firing along "check lines" is practiced. Mr. Willis S. Jones, of Claremont, Calif., is the originator of this plan and has had great success with it on his own 40-acre orange grove. His plan is as follows (see fig. 8):

The air movement in his grove is generally steady and is normally from the north. It sometimes shifts to the northeast and east, but practically never blows from a southerly or westerly direction. On the northern and eastern borders of the grove three short-stack citrus heaters are placed to each tree, and on the line immediately inside

these heaters are placed one to a tree. The remainder of the orchard is divided into checks 16 trees square and a double row of heaters is distributed along each check line. The remainder of 3,800 heaters are placed one to each tree in the colder parts of the orchard and one to two trees in the remainder of the orchard.

When the time to fire arrives, the direction of the air drift is noted, and the outside row to windward is fired first so that the heat

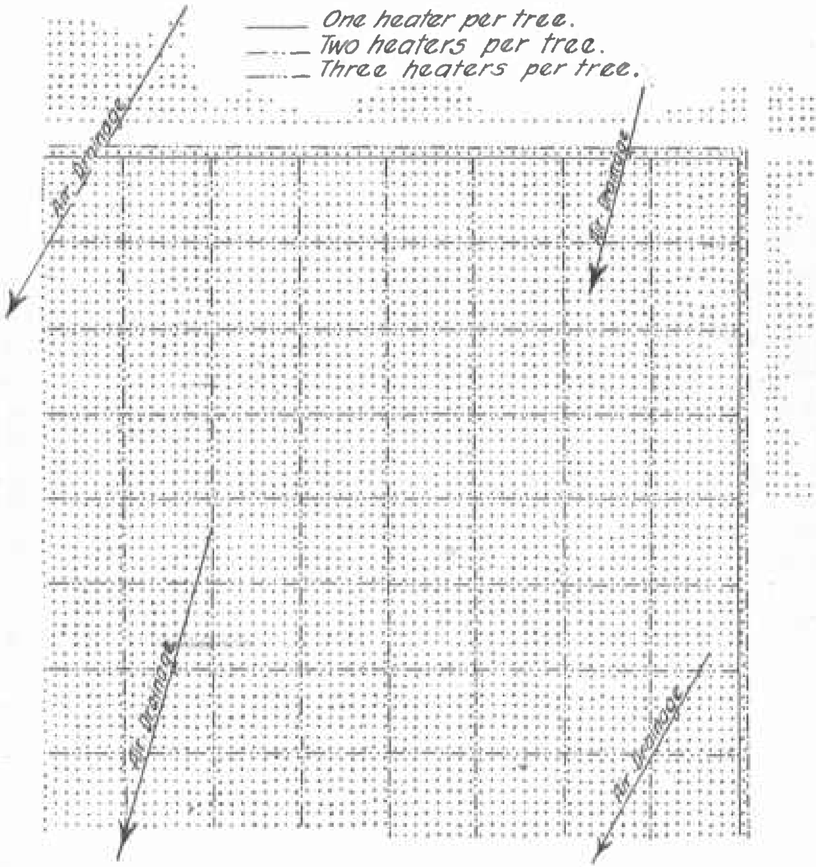


FIG. 8.—Diagram of 40-acre orange grove owned by Willis S. Jones, near Claremont, Calif., illustrating his system of firing orchard heaters along check lines. Dots represent orange trees, spaced 20 feet apart on the square. The normal direction of the air drift on cold nights is shown by the arrows.

is carried into the orchard. (See fig. 9.) Three more east and west lines are fired immediately afterwards, and if the temperature continues to fall, three north and south lines are fired. The 40 acres are then divided into 16 checks of 256 trees each, surrounded on all sides except the extreme west and south by lines of fires 20 feet apart. If the temperature still remains low in the colder parts of the orchard,

the eighth rows east and west are fired. This has been necessary on only two occasions in four years. During the four seasons from 1914 to 1917, more than 580 heaters were never lighted at one time on the 40 acres. The heaters are burned at their maximum rate at all times. Mr. Jones advocates this system of firing on account of—

1. Easy and rapid lighting; one man can light 250 to 300 heaters per hour.
2. Easy and rapid refilling the next day.

The firing on the 40-acre grove is easily handled by two men.

In experiments carried on during the winter of 1918–19 in cooperation with the Pomona Valley Frost Protective Association and Mr. Jones it was found that the temperature 5 feet above the

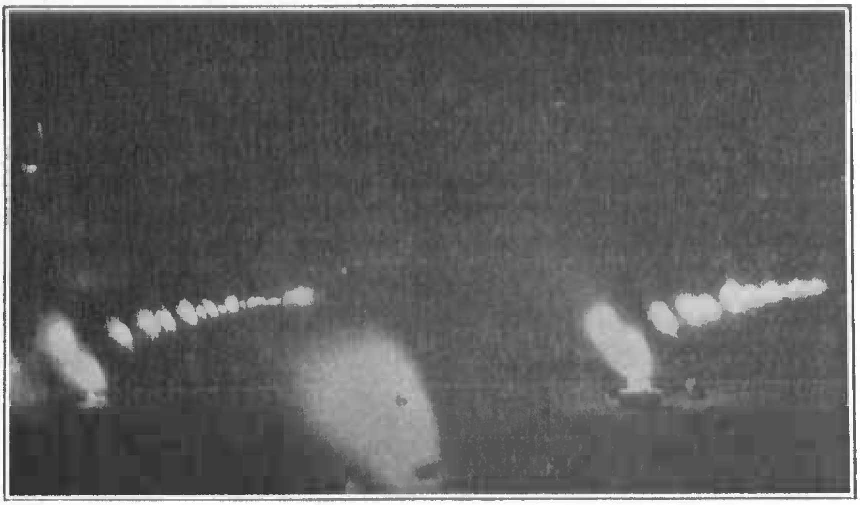


FIG. 9.—Outer check line of fires on the north of Willis S. Jones orchard, photographed about 3.30 a. m. on a cold morning. An exposure of about 15 minutes was required. The absence of any flame on the right (north) side of the heaters indicates the steadiness of the air drift.

ground and 70 feet inside the two outside check rows can be raised from 2° to 4°. With several check rows across the line of drift burning it is probable the temperature at the leeward side of the orchard is raised a somewhat greater amount. In adopting this system of firing, the space between the check lines should contain at least one heater to every two trees for use in an emergency, when the fires on the check lines may fail to hold the temperature above the danger point.

The heated air from a fired orchard often drifts through neighboring orchards which are not fired, affording them in some cases even more protection than the fired orchard itself. (See figs. 10 and 11.)

Number of Heaters per Acre.—The number of heaters to the acre necessary for protection depends on the location of the orchard with

regard to surrounding topography. For deciduous orchards in the colder sections there should be not less than 100 of the 5-quart lard-pail heaters to the acre, and if exceptional cold is likely to be experienced frequently, about 140 to the acre should be used. Of course all the heaters are practically never lighted at once; some are always held in reserve to be used when others burn out. In the warmer deciduous fruit regions, where the temperature is not likely to fall below 25° at any time, these heaters should be set about 80 to the acre.

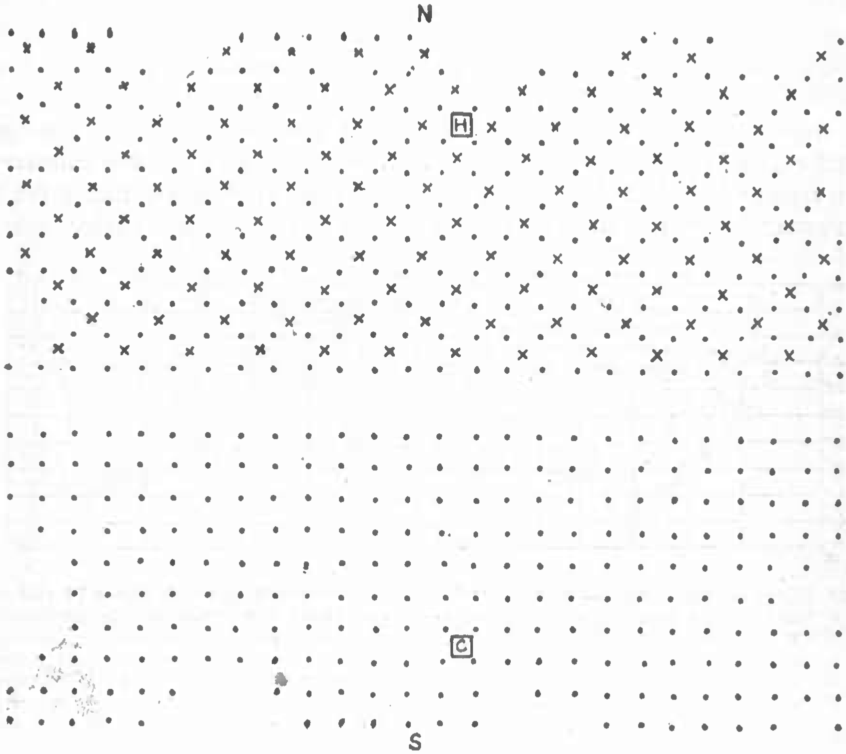


FIG. 10.—Plan of lemon groves where temperature records shown in figure 11 were obtained. Dots represent lemon trees, spaced 20 feet apart; crosses represent high-stack oil heaters. Squares marked H and C show locations of thermometers in heated and unheated groves, respectively.

The number should not be much less if 2-gallon lard-pail heaters are used. The larger heaters have a longer burning time, but the amount of heat released in a given time is not much greater. (See fig. 12.)

The number of the newer improved type of heater necessary for protection depends on the location of the orchard and on the kind of fruit to be protected. Orange groves on low ground, where temperatures as low as 20° may occur as often as every five or six years, should have at least one large capacity heater to each tree. On the higher slopes the number may be reduced to 80 per acre, but if ex-

tremely heavy frosts, like those of 1913 in California, are to be fought successfully, dependence should not be placed on a much smaller number. Some growers have successfully protected their orange crops for several years with as few as 30 or 40 heaters to the acre, but no exceptionally heavy frosts occurred during that time. (See figs. 13 and 14.)

Lemons are more susceptible to frost damage than oranges, but where a large acreage is protected it is usually possible to save the large fruit with 100 large capacity heaters to the acre when the temperature falls to 19°. A portion of the blossoms and young fruit is likely to be frozen when the temperature remains at this point for five or six hours, even with 100 heaters to the acre.

Care of Oil Heaters.—The amount of attention given to storage and care of oil heaters varies greatly in different parts of the country. In parts of California where the annual rainfall is light, many fruit growers leave the heaters in the orchards during the entire year,

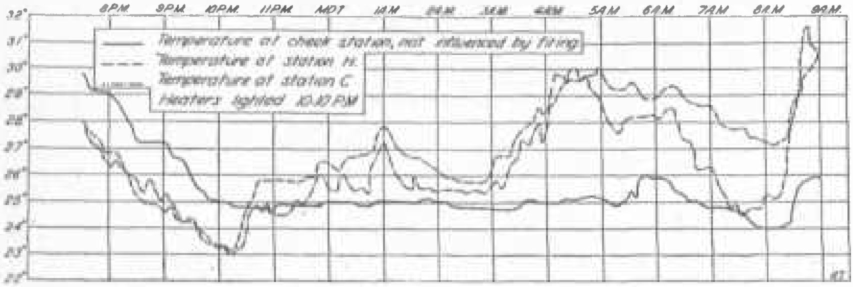


Fig. 11.—Continuous records of the temperature at stations H and C in figure 10 and at a third station located in an unheated orchard about 500 yards to the southeast. When the fires were lighted at station H about 10 p. m., the warmed air drifting across to station C raised the temperature there almost as much as at station H inside the fired area. At the end of the season the fruit at station C was in better condition than that at station H, due to the protection afforded by the firing in the neighboring grove. Note that the temperature at stations H and C ran nearly 2° lower than at the third station before the fires were lighted.

setting them up close to the trunks of the trees after the danger of frost is past. Trees are sometimes injured or even killed through oil from leaky heaters penetrating the soil around the roots. For this reason, heaters left in the orchard should be emptied at the end of the season. Lard-pail heaters are usually covered with a film of oil, which helps to prevent rusting, and the rate of deterioration is little, if any, greater than is the case when they are stored under cover. Where there is considerable annual rainfall, lard-pail heaters should be emptied, dipped in heavy oil, and stored under cover when not in use. With ordinary care heaters of this type will last 10 years or longer. Several orchardists have used them 14 and even 16 years without losing more than a small percentage through deteriora-

tion. Some fruit growers prevent contact between the bottoms of the heaters and the ground by placing the heaters on small square pieces of board.

The cost of the larger heaters is so great that it is good practice to give each one a coat of good stack paint at intervals of 2 or 3 years to prolong its life. Mr. Willis S. Jones, of Claremont, Calif., has his heaters thoroughly brushed with a steel brush to remove rust and dirt. Each heater is then placed on an iron grating under which one or two heaters are burning until it is brought to a high temperature, after which the paint is applied hot.

At the end of each season the heaters usually contain a small quantity of a mixture of soot and asphaltum, which sticks to the bottom

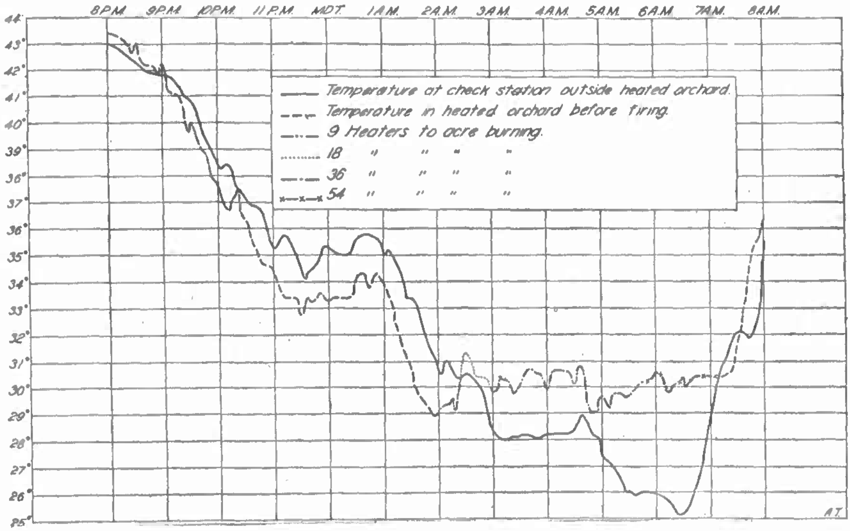


FIG. 12.—Continuous records of the temperature inside and outside a heated pear orchard, showing the effect of the firing on the temperature. Five-quart lard-pail oil heaters were used. Note that the temperature in the heated orchard ran about 2° lower than at the check station before the heaters were lighted.

and is difficult to remove when cold. The usual method of removing this material has been to burn it out with distillate. In doing this accidents often occur and piles of several hundred or more heaters sometimes catch fire, ruining the heaters and endangering surrounding property.

At the Bear Creek Orchard, Medford, Oreg., the manager, Mr. B. B. Lowry, has a trench covered with sheet iron on which he treats the empty heaters at the end of the season. A fire is built under the iron, using the residue from the heaters for fuel, which burns fiercely. A large inclined flue carries away the smoke from the fire and creates a draft. The heaters, a dozen at a time, are placed on the sheet iron

until they become hot and the residue is loosened, when they are removed with tongs one by one and rapped against a post, causing the residue to fall out. They are then examined for leaks by holding them upward toward the sun. The work can be handled very rapidly in this way and there is little danger of accident.

Coal Heaters.—Coal is burned in open piles on the ground, in wire baskets and in specially designed sheet-iron heaters. Coal heaters possess some advantages over oil heaters in that the heat can be applied near the ground, there is no strong up-draft and usually not much soot or smoke after the first few minutes of burning. On the other hand, coal fires are often difficult to light and hard to regulate; the fires often have a tendency to smolder slowly or burn out

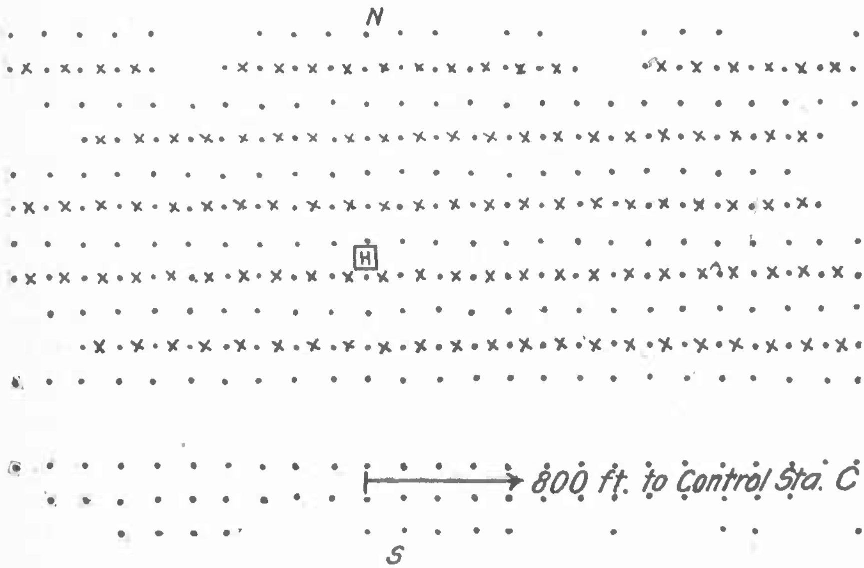


FIG. 13.—Plan of orange grove where temperature records shown in figure 14 were obtained. Dots represent orange trees spaced 20 feet apart; crosses represent low-stack oil heaters. The square marked H shows location of thermometers in fired orchard. The check station was located about 800 feet to the eastward to avoid the influence of the fires. The air drift on cold nights was normally from a northerly direction.

with a rush. When firing is required for several hours it is necessary to replenish the fuel in the heaters. The labor costs are relatively high, as a large number of men are required to attend to this work. In California reserve supplies of coal for each heater are kept in wooden boxes set under the trees. At the end of the season the heaters are placed on top of these boxes and are left out all the year.

The number of coal fires to the acre should be about the same as when the lard-pail oil heaters are used.

Lighting Equipment.—Orchard heaters of all kinds can be lighted easily and rapidly with torches burning a mixture of gasoline and

distillate or gasoline and fuel oil. (See fig. 7.) These torches drop the burning liquid into the heaters, starting combustion immediately. Lard-pail heaters when new are sometimes difficult to light. If the burning liquid from the torch is poured in a ring on the edge of the heater, no difficulty will be experienced. After three or four firings the carbon deposited on the rim of the heater acts as a wick and a little burning liquid dropped anywhere in the oil will ignite it readily.

Many fruit-growers hire school boys to light the heaters and have been able to place great dependence on them.

Coal fires should be carefully built up with oil-soaked waste or paper and a small amount of kindling. If a portion of the fires fail to burn a great deal of valuable time is lost in going back over the same territory again.

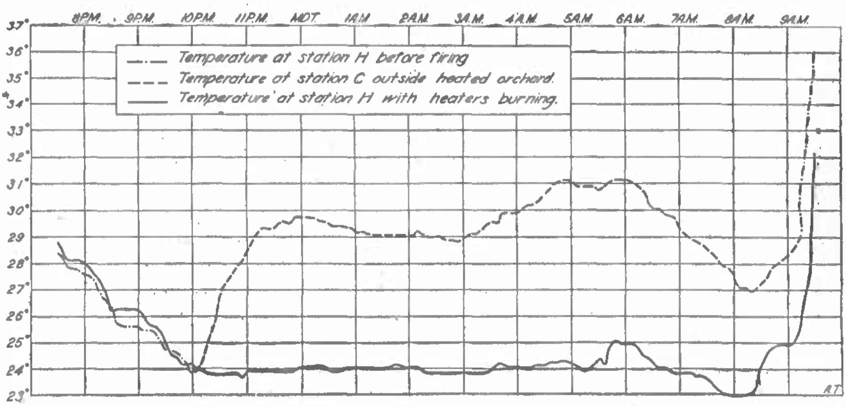


FIG. 14.—Continuous records of the temperature at stations shown in figure 13, showing the effect of firing on the temperature. Low-stack oil heaters of the type shown in figure 6 were used.

Storage of Fuel.—In order to carry on orchard heating successfully it is necessary to have enough fuel within reach to last through the longest cold spell likely to be experienced. Too many instances have been noted where the crop has been protected successfully through several cold nights at considerable expense, only to be lost on one cold night on account of lack of fuel. Where orchard heating is practiced by many growers in a community it is a good plan to buy and store large quantities of fuel oil on a cooperative basis, as is done in southern California. Orchards located near the storage tanks can haul directly from them, but in the case of those located a mile or more distant, storage tanks should be provided in the orchard.

The necessity of pumping oil from storage tanks should be avoided by raising the tanks high enough above the ground so that the oil

will flow into the wagon tanks by gravity. Where the ground is not too flat, the storage tank can be so located that the oil can be put into it and taken out by gravity. If more than 5 acres are to be fired with oil a portable tank from which to fill the heaters is almost a necessity on account of the saving in time and labor. Three men with a tank wagon can fill heaters very rapidly, one man driving and two men drawing oil into 5-gallon buckets and pouring it into the heaters, filling two rows at the same time. The owners of two adjoining orchards often use the same tank wagon.

Owners of small orchards often handle the oil in metal drums of about 50 gallons capacity. The heaters are filled directly from the drums, which are hauled through the orchard on sleds.

IS ORCHARD HEATING PROFITABLE?

This question can be answered only by the individual grower, as the factors to be considered in drawing a conclusion vary greatly, sometimes even for orchards within a few miles of one another.

The most important points to be considered are as follows:

1. What has been the average loss from frost damage in your orchard during a period of years—as long a time as possible? Unless these data are available from personal experience they will usually be difficult, if not impossible, to obtain, although neighboring fruit growers may sometimes be able to supply some information. As a general rule, few records of this kind have been kept.
2. How many times during this period of years would it have been necessary to light the heaters in order to have saved the entire crop each year? If dependable temperature records have been kept for a number of years somewhere in the immediate vicinity and are still being kept at the same location, a comparison of records from the orchard and from the station with the long record for the same season may make it possible to gain a fairly accurate conception of what temperatures have been experienced at the orchard in question.
3. Will the value of the fruit lost through frost damage more than pay interest and depreciation charges on an investment for all necessary heating equipment, together with all costs of operation?
4. Is your locality likely to be visited by short periods of extremely cold weather during the growing season that may badly injure or kill the trees? This question can probably be determined from Weather Bureau records from some station in the vicinity.

There are two conditions under which orchard heating will not be profitable. The orchard may be located where frost damage is too slight in the long run to pay the expenses of heating, or the orchard may be in an exceptionally cold section where damaging frosts occur so often that the costs of protection are too great to be borne by the crops.

The number of cases of the first-mentioned type is smaller than would appear at first thought. The saving of one season's crop, which would otherwise have been a total loss, will justify the expense of heating for a good many years. Some practical growers consider it

good business policy to have frost-fighting equipment, even though it is necessary to use it only one season out of five.

In cases of the second type it is obvious that the frost hazard is so great that fruit growing will not be profitable in the long run and the trees will eventually have to be removed.

The statement is often made that the policy of growing fruit on the colder low ground is wrong and that orchards should be confined to the higher and more frost-free locations. This is not always true. In some parts of southern California the difference in the cost of irrigation more than makes up for the expense of protecting the orchards on the lower ground from frost. In addition to this the cost of cultivating steep hillsides is greater. The same is true of certain deciduous fruit districts in Oregon.

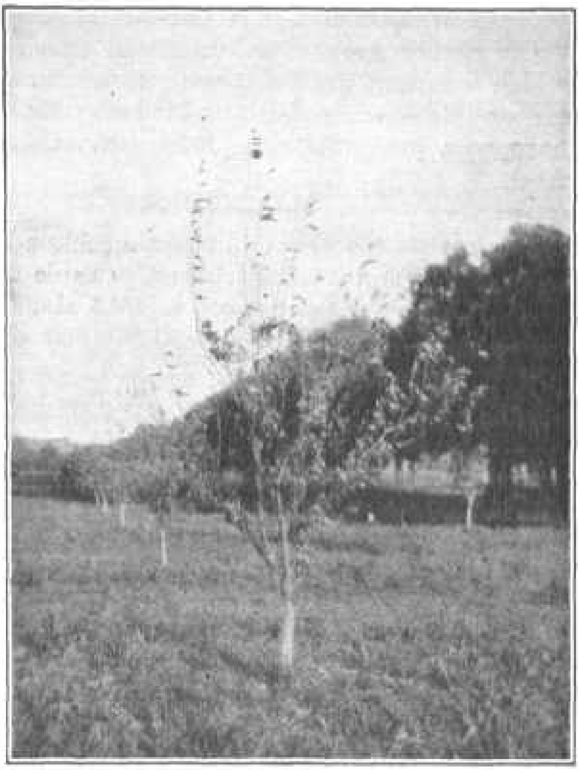


FIG. 15.—Young lemon tree almost entirely stripped of foliage by frost. The fruit was a total loss and most of the the remaining leaves dropped later.

On a farm near San Francisco potatoes have been grown successfully during the winter months for several years with the aid of open lard-pail oil heaters. Irrigation water necessary for crops grown during the summer is scarce and expensive, while the rainfall during the winter months is ample. The new crop is harvested in the spring, and reaches the market so early that exceptionally good prices are obtained.

The degree of success attained in protecting potatoes at this place indicates that low-lying crops may be protected against ordinary spring frosts by using the small open lard-pail heaters, set from 60 to 80 to the acre. In addition to the heating of the air over the plants, the direct radiation of heat from the heaters

aids considerably in protecting the plants immediately surrounding them. In planting a field to a low-growing crop that is to be protected with heaters, vacant spaces about 18 inches square should be left at the points where the heaters are to be placed, as the plants very close to the heaters are likely to be scorched.

Orchard heating has been practiced for six years on one of the largest lemon groves in the country, located in southern California. During the season of 1912–13, a season when the citrus crop in many parts of southern California was practically a total loss and thousands of trees were killed outright, the lemon crop from this grove brought $734,318.07 f. o. b. California.

On higher ground on the same ranch 5-year-old lemon trees which were not protected were frozen to the ground. The manager of this ranch states it is his belief that the business would not have been profitable since 1912 without means of protection from frost.

MAXIMUM COST OF FIRING

Records on the cost of protecting 220 acres on this place during the past six years are shown below. (Table 1.) It will be seen that the returns from the fruit saved in 1913 alone would pay the costs of protection for many years. About 500 acres of lemons are now being protected here.

TABLE 1.—*Average cost per acre for protecting 220 acres of lemons with oil heaters.*[1]

	Year.						Total 6-year average, per acre.
	1913	1914	1915	1916	1917	1918	
Labor, man and horse, filling and lighting pots, per acre	$45.70	$10.55	$10.65	$21.45	$20.60	$22.15	$21.85
Oil	38.35	12.70	4.20	23.20	26.15	17.75	19.55
Depreciation	19.30	19.10	17.40	15.60	14.30	13.00	16.45
Interest	17.85	17.45	15.50	13.40	13.45	11.25	14.80
Upkeep	11.55	7.95	7.65	1.10	5.65	3.70	6.25
Total	132.75	67.75	55.40	74.75	80.15	67.85	78.90
Number of times fired	19	2	7	20	27	21	

[1] Small open heaters used in 1913; down-draft, short stack type in later seasons.

This ranch is located on both high and low ground, but only the low ground is protected. Lemons are more easily damaged than oranges, and as the small green fruit is protected here, the fires are lighted oftener than in most other orchards. The costs given above are for firing about the maximum number of times that would be necessary anywhere in the country.

AVERAGE COST OF FIRING

Mr. Willis S. Jones, of Claremont, Calif., has kept accurate records on the cost of firing his 40-acre orange grove, which is on rather

high ground and is fired only a few nights each year as a general rule. These cost figures, given below (Table 2), are for firing a number of times per year which is probably slightly below the average.

It is impossible to estimate present-day costs of equipping an orchard from any of the above figures on account of the increase in the price of all materials used in the manufacture of heaters and other equipment.

Mr. Jones's orchard was not equipped with heaters in 1913 and his crop was a total loss. At the prices prevailing at that time he estimates he lost fully $10,000 worth of fruit in the two seasons prior to 1913, and $25,000 worth of fruit in 1913. In addition, so many of his trees were severely damaged that he experienced a heavy loss in reduced crops during the next several years. Since putting in heating equipment, including the severe season of 1918–19, his losses from frost damage have been negligible.

TABLE 2.—*Detailed costs of protecting 40 acres of oranges with oil heaters.*

EQUIPMENT INSTALLED NOVEMBER AND DECEMBER, 1913.

Storage:		
21,000-gallon galvanized iron tank	$298.90	
Concrete foundation	45.92	
Pipe line	164.46	
Laying pipe line	7.85	
		$517.13
Distributing system:		
Wagon	51.50	
Two 575-gallon tanks, complete	161.70	
4 buckets	6.20	
1 dozen lighting torches	9.00	
		228.40
Heaters:		
3,800 heaters at $0.58	2,204.00	
Painting heaters at $0.02	76.00	
		2,280.00
Thermometers	42.00	
		42.00
Total investment		3,067.00

OPERATING EXPENSES.

Interest:			
6 per cent on $3,067, original cost			$182.85
Depreciation:			
Storage tank, 5 per cent on $298.90	$14.93		
Pipe line, 3 per cent on $164.46	4.93		
Wagon, 10 per cent on $51.15	5.15		
Wagon tanks, 8 per cent on $161.70	12.93		
Buckets and torches, 20 per cent on $15.20	3.04		
Heaters, 12½ per cent on $2,204	275.50		
Thermometers, 5 per cent on $42	2.10		
			318.58
Operation:			
Oil, 1913, 25,095 gallons at $0.03	752.85		
Hauling, at $1.50 per 1,000	37.63		
		$790.48	

TABLE 2.—*Detailed costs of protecting 40 acres of oranges with oil heaters*—Con.

OPERATING EXPENSES—Continued.

Operation—Continued.			
Oil, 1914, 13,725 gallons at $0.03	$401.75		
Hauling, at $1.50 per 1,000	20.58		
		$422.33	
Oil, 1915, 575 gallons at $0.03	17.25		
Hauling, at $1.50 per 1,000	.75		
		18.00	
Oil, 1916, 15,525 gallons at $0.04	621.00		
Hauling, at $1.50 per 1,000	23.28		
		644.28	
Total for four years		1,875.09	
Credit oil on hand, 17,173 gallons, at $0.04	686.92		
Hauling, at $1.50 per 1,000	25.75		
		712.67	
Net cost, 4 years		1,162.42	
Average cost per year			$290.60
Distributing, filling, firing, taking in, cleaning, and painting heaters:			
1913–14		199.88	
1914–15		204.63	
1915–16		340.90	
1916–17		336.70	
Total cost for four years		1,082.11	
Average cost per year			270.52
Total annual cost for 40 acres			1,062.55
Average annual cost per acre			26.56

Detailed average annual cost per acre.

Interest	$4.57	
Depreciation	7.96	
Operation:		
Fuel	7.26	
Labor	6.76	
		$26.55

BEST METHODS OF HANDLING ORCHARD HEATING

The fact can not be emphasized too strongly that if orchard heating is to be practiced successfully, it must be handled with as much care and attention as spraying, fumigating, or any other necessary farm work. The secret of success will be found in adequate equipment, good judgment, attention to detail, and extreme vigilance. An inadequate number of fires to the acre may often be worse than none at all, as the costs of firing may have to be added to the loss of the crop.

Whenever the temperature approaches the danger point the thermometer *in the orchard* should be watched closely and, if possible, the rate at which the temperature is falling should be determined. If the temperature is falling rapidly the firing must be begun early if the heaters are to be all lighted before the danger point is reached. With a little practice it is often possible to tell with considerable accuracy by inspection of the fruit or blossoms,

when the danger point has been reached, regardless of the temperature.

When small apples or pears commence to freeze minute blisters will begin to form on the skin. By keeping constantly on the watch for the first appearance of these blisters on the fruit in the coldest part of the orchard, the firing can be begun at exactly the right time; no fruit will be lost and no oil wasted. By carefully cutting the blossoms of deciduous fruit it is generally possible to note with ice crystals first begin to form in them, and thus regulate the beginning of firing.

When oranges begin to freeze, the section of the skin exposed to the sky takes on a transparent appearance, generally known as the "water-mark," probably caused by the water in the rind freezing and leaving the oil separated. On the following day these oranges can be picked out easily and are called "shiners." By timing the firing with the first appearance of the "water-mark" in the orchard, it is possible to save the fruit and yet prevent waste of oil. Some experience is necessary before the fruit grower is able to use these methods of timing the firing; but the importance of saving oil is well worth giving the matter close attention.

If the small lard-pail heaters are set 100 to the acre, alternate heaters in every fourth row should be lighted first, followed immediately by alternate heaters in every second row if the temperature has been falling rapidly. The effect on the temperature should then be noted and decision made as to whether additional firing is necessary at that time. As soon as a row of heaters begins to burn low, reserve heaters should be lighted, as the amount of heat given off during the last half hour of burning is small.

If the large capacity down-draft heaters are used, all may be lighted at once if desired and the consumption of oil regulated by manipulating the drafts.

During a cold night an isolated cloud passing overhead, by cutting off radiation and to a certain extent reflecting radiation from the earth, may cause the temperature to rise. As the cloud drifts toward the horizon the temperature falls again. Likewise, sudden temporary rises in temperature are caused by gusts of wind of short duration which mix the upper and the surface air. As a general rule the temperature falls rapidly after the wind or cloud has passed and cases are on record where entire crops were lost through extinguishing the heaters at such a time. If clouds are overspreading the whole sky or a sudden rise in temperature due to wind occurs just before sunrise, the heaters may be extinguished, but if the sky remains clear and sunrise is an hour or more away, the temperature should be watched closely during the remainder of the night.

Although it is sometimes difficult to find time to keep records on heating operations during the rush of firing, it should be done whenever possible. The temperature when firing is begun, time of initial firing and number of heaters fired, time of firing additional heaters, the lowest temperature recorded during the night, can all be jotted down from time to time as the work goes on. On the following day an estimate can be made of the amount of oil consumed and the extent of the damage to the fruit, if any. Records of this kind will be found to be of great value in regulating later firing; the more information of this kind gathered, the more efficiently can the firing be handled. Records of this kind will also help to determine whether protection is profitable or not, a question which every grower should solve for himself at the earliest possible time.

If orchard heating is carried on in a careful, painstaking manner, with ample equipment, there are probably few commercial fruit-growing districts where the heaviest frost likely to be experienced can not be successfully fought with orchard heaters.

FROST AND MINIMUM TEMPERATURE FORECASTS

General forecasts of frost for large areas are issued by the Weather Bureau during the growing season, and in certain rather small districts where protection against frost damage is practiced on a large scale, forecasts of the minimum temperature to be expected from night to night are issued. Farmers or fruitgrowers who have a means of protecting their crops should arrange with the nearest Weather Bureau station to obtain forecasts of the kind available in their community.

INJURIOUS TEMPERATURES

So many factors must be taken into consideration in determining whether a given temperature will cause damage that the matter is one of great complexity. The length of time the low temperature persists, the vigor and stage of advancement of the plant, the kind of weather preceding the frost, and the rate of thawing all have considerable influence on the amount of damage that will be done. Other conditions being the same, a weak, undernourished plant will show more injury than a strong healthy one after both have been subjected to the same low temperature.

Pure water has a higher freezing point than water carrying foreign substances in solution. For example, the freezing point of a strong solution of common salt may be 23° or lower, depending on the concentration; the weaker the solution the higher the freezing point. When the weather is warm and sunshine and moisture plentiful, plants make a rapid growth and the sap is likely to be

watery and its freezing point high. For this reason a frost which follows a period of weather favorable for rapid growth will cause more damage than the same frost following a period of cold cloudy weather and consequent slow growth.

When a plant freezes a portion of the cell sap is withdrawn from the plant cells, gathering in the intercellular spaces in the form of ice. If thawing takes place gradually and the cell walls have not been ruptured, this moisture is again taken up by the cells as it is melted, without serious damage. If thawing takes place rapidly, however, the intercellular ice is liquefied faster than it can be absorbed by the cells; a part of it is lost by evaporation and the cells are broken down. When fruit crops are damaged by frost the greatest damage is often found on the portion of the tree where the morning sun strikes first. When clouds gather on the eastern horizon before sunrise and obscure the sun for a few hours in the morning after a cold night, damage to vegetation is likely to be slight, provided the temperature does not fall much below the critical temperature. Heavy smoke from orchard heaters or smudge fires may also lessen damage from frost through causing a slow thawing. Of course, if the temperature falls sufficiently low a great deal of damage may be done even when the rate of thawing is slow; in other words, the prevention of a rapid rise in temperature in the morning may often not be sufficient in itself to prevent injury.

It is possible that some of the protection from frost damage obtained by irrigating is due to making available to the damaged plant cells a larger supply of water through increased flow of sap, to replace that lost through freezing.

INFLUENCE OF HUMIDITY ON RATE OF FREEZING

Fruit growers in nearly all sections are convinced that with the same temperature the amount of damage by frost will be greater when the humidity is low than when it is high. Recent studies by I. G. McBeth, of the Leffingwell Rancho at Whittier, Calif., indicate that under certain conditions citrus fruits will be damaged in a shorter time when the humidity is high than when it is low, the temperature being the same in both instances. It was thought this was due to greater conductivity of moist air, the heat being conducted away from the fruit more rapidly, causing the temperature of the fruit to fall more nearly at the rate at which the temperature of the air was falling.

However, in making these investigations allowance was not made for the influences of radiation and the liberation of heat by condensation. Under orchard conditions, blossoms and leaves exposed to the sky lose their heat rapidly by radiation and their temperature may

fall several degrees below that of the surrounding air. The temperature of mature citrus fruits falls more slowly than that of the surrounding air but the rate of fall follows more closely that of the outside air when radiation is rapid than when it is slow. Growers of citrus fruits are familiar with the fact that the first fruit to be damaged is that which is exposed to the sky; fruit on the interior of the tree and screened from the sky by leaves or branches often will show no injury with air temperatures several degrees lower. Radiation goes on more rapidly when the air is relatively dry than when it is moist and the temperature of the fruit is likely to follow more nearly that of the surrounding air when the humidity is low.

On nights when the humidity is high, considerable ice is deposited on the fruit or blossoms. When this moisture condenses and freezes, some of the latent heat liberated tends to retard the rate of fall in temperature of the fruit. After sunrise the thawing of the ice and evaporation of the resulting water retard the thawing to a slight extent and this has a tendency to lessen the damage.

It is possible that under actual orchard conditions, these influences which tend to lessen the amount of damage on a night with relatively high humidity more than counteract the influence of the increased conductivity of the moist air.

DECIDUOUS FRUITS

Damage by frost to deciduous fruits usually takes place in the spring when the trees are in bud or blossom or shortly after the fruit has set. The stage of advancement is of the greatest importance in estimating resistance to low temperature; the same degree of frost that causes little or no damage to fruit in bud, may injure the greater portion of the crop two or three days later.

In the case of most deciduous fruits, the same temperature will cause far more permanent damage after the fruit has set than during the period when the trees are in full bloom, and the later the frost after the fruit has set, the greater is the actual loss. This is due to the fact that there is nearly always a great overproduction of bloom and usually from 50 to 90 per cent of the blossoms can be killed without materially reducing the final crop of fruit. This fact often causes orchardists to overestimate the amount of damage to their crops early in the season. One or two uninjured blossoms in each cluster are usually enough for a good crop. With some small fruits and nuts a larger percentage of the blossoms must mature in order to obtain a full crop and damage during full bloom is more serious.

Another point to be considered is the fact that the blossoms do not all open at once; there are often unopened buds and small fruits on the trees at the same time. Even though a heavy frost at this

stage may kill all or most of the more advanced blossoms, there may still be a sufficient number of unopened buds left to insure a crop of nearly normal size. However, fruit from late bloom is usually undersized and of poor quality.

In the process of natural thinning the number of fruits on the trees is steadily and rapidly reduced after the period of full bloom and the loss of a large percentage of the fruit retained on the tree at this time is likely to reduce seriously the size of the crop harvested.

It is obvious from the above that the greatest need for protection comes after the period of full bloom. While a single night's frost during the period of full bloom may not seriously reduce the size of the final crop of apples, peaches, apricots, or pears, when the amount of bloom is reasonably heavy, each one of a series of heavy frosts at this period may kill a certain portion of the remaining uninjured blossoms, until not enough sound blossoms are left to make a full crop. Where an orchard is equipped with heating devices the only safe policy is to hold the temperature high enough at all times so that only a few blossoms will be injured.

Apples and pears are often badly injured by frost but remain on the trees and mature. Such fruits are mis-shapen and more or less seedless and are not marketable as first grade. Frosted pears enlarge abnormally near the stem and lose their characteristic pear shape, while injured apples become rough and their shape irregular. Injured fruit of this kind often remains on the trees until a month before maturity and then drops.

The blackening of the centers of blossoms or of small apples and pears does not necessarily mean that they will not mature, though the chances are greatly in favor of their dropping before the end of the season. The injured tissue is often gradually absorbed until the blackening entirely disappears.

Different varieties of the same fruit often differ considerably in degree of resistance to frost damage and when the same critical temperature is given for all varieties, it is applicable only in a very general way. The best possible arrangement to be followed by the orchardist who protects his orchard is to keep in touch with the local county agricultural agent or horticultural commissioner as the season progresses and obtain opinions from him from time to time as to the temperatures that will cause damage. These officials are likely to have had considerable experience in noting the effect of low temperature in the local district and are also familiar with the condition of the fruit or blossoms as they have been affected by previous weather conditions.

It will pay the individual grower to keep careful records of the temperature in his orchard on cold nights, together with notes on

the effect on the size of the final crop. After a few seasons, he will have collected enough data to enable him to know with considerable accuracy how low it is safe to allow the temperature to fall before lighting the heaters.

The following table of critical temperatures as recorded by a well exposed thermometer in the orchard is meant to give a general idea of what the blossoms will endure for a half hour or less without injury.

Temperatures endured by blossoms for 30 minutes or less.

Fruit.	Closed but showing color.	Full bloom.	After fruit has set.
	°F.	°F.	°F.
Apples	25	28	29
Peaches	25	26	28
Cherries	25	28	30
Pears	[1] 25	28	30
Plums	25	28	30
Apricots	25	27	30
Prunes	28	29	30
Almonds	26	27	30
Grapes	30	31	31

[1] Bosc 27.

CITRUS FRUITS.

Owing to the lateness of the blossoming period of most varieties of oranges, the fruit has practically reached maturity before the frost season arrives in the subtropical sections where they are grown commercially. In this case, therefore, we have to deal with the chilling of a relatively large bulk in comparison with deciduous fruit or blossoms.

The thick pithy rind of the orange is a poor conductor of heat and the protection it affords causes the temperature of the interior to fall much more slowly than the temperature of the outside air. When the air temperature is falling rapidly the interior of the fruit may be as much as 7° warmer than the air surrounding it, and the temperature inside the fruit lags from an hour to an hour and a half behind the temperature of the air. As the freezing point of orange juice is about 28° F., the temperature inside the fruit will not fall much below this point until the fruit is frozen. (See fig. 16.) It is characteristic of any liquid that in the freezing process sufficient latent heat is given off to maintain the temperature at the freezing point of the liquid until the whole quantity of liquid has been frozen.

Radiation is of great importance in damaging citrus fruit and the fruit exposed to the sky is always the first to be frozen. It is probable that any beneficial effects that may be obtained by covering an orchard or tree are due in a large degree to diminishing the rate of

radiation from the fruit so that the fall in temperature inside the fruit lags considerably behind that of the air.

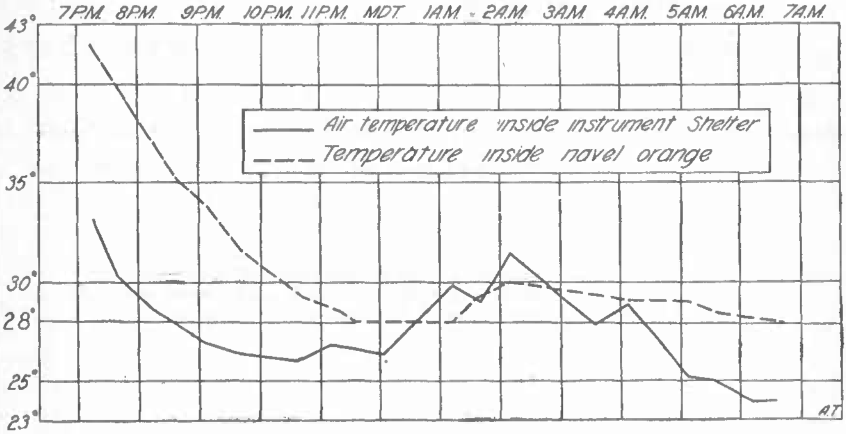


FIG. 16.—Eye readings of the temperature inside a 3½-inch mature navel orange on the tree exposed to the sky, compared with simultaneous readings of the air temperature inside a standard thermometer shelter at the same height above the ground. Note that the temperature inside the fruit did not fall below 28°, which is approximately the freezing point of the juice.

The critical temperature for nearly ripe oranges is most often given as 26° F. to 27° F. During the winter of 1918–19, however, two navel orange groves in southern California experienced air temperatures on different nights as shown in figure 17.

Comparative figures on the amount of damage in the two groves are given below:

Comparison of damage to two groves.

	Grove No. 1.		Grove No. 2.	
	Pounds.	Per cent.	Pounds.	Per cent.
Total fruit harvested	190,975	....	188,230	....
Extra choice	123,075	64	86,800	46
Choice	58,585	31	35,935	19
Partly frozen [1]	0	0	55,170	29
Culls (all sources)[2]	9,315	5	10,325	6
Eliminated (frozen fruit)[3]	0	0	5,400	3

[1] Fruit with up to 15 per cent of tissue 15 per cent frozen marketed in this grade, which brought from 40 to 70 per cent of the price received for undamaged fruit.
[2] Includes misshapen fruit, frozen fruit, etc., total loss.
[3] More than 15 per cent of tissue 15 per cent frozen. This fruit is a total loss.

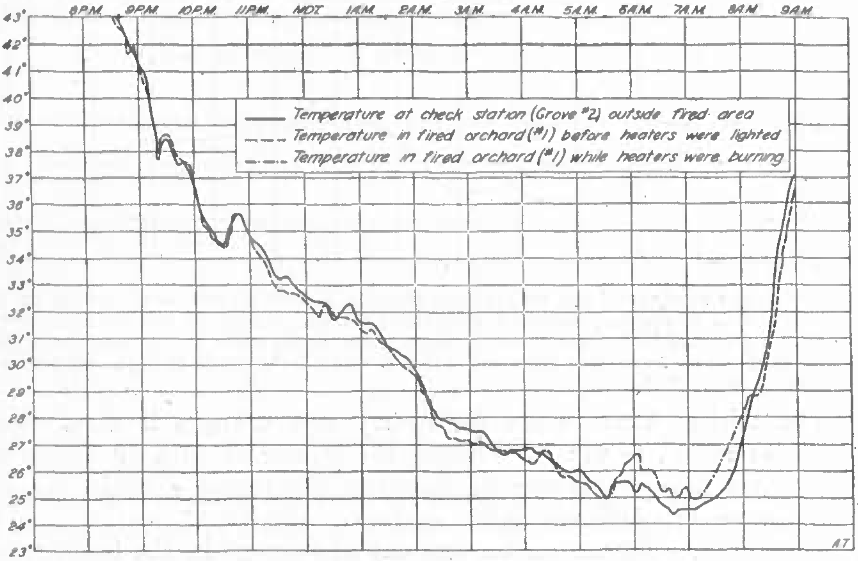
The fruit in grove No. 2 was of a much better quality before the first frost than that in grove No. 1, which accounts for the large amount of culls, not frozen, in grove No. 1. If there had been no damage from frost the amount of fruit marketed as "extra choice" and "choice" would have been much larger in grove No. 2 than in grove No. 1.

Green oranges are injured at considerably higher temperatures, their critical temperature being between 28° F. and 29° F.

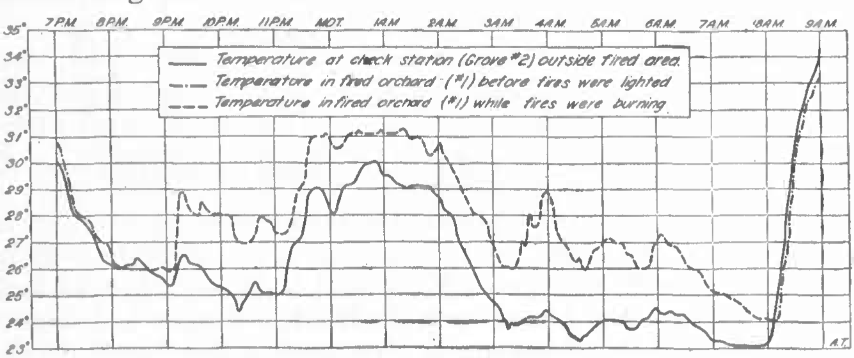
Small green lemons are injured when the temperature remains at 29° F. for some time. Ripe lemons are damaged at 27° F. Lemon blossoms are killed at about 30° F.

METEOROLOGICAL INSTRUMENTS AND EXPOSURES

It has been stated that substances when exposed to a clear sky, steadily lose heat by radiation. Not only does the rate at which ra-



diation takes place vary greatly on different nights, but every individual substance has its own rate at which it radiates heat. Therefore, under conditions favorable for radiation, a thermometer of dark metal would show a lower temperature than one of mercury inclosed in glass.



The only method whereby temperature measurements which are at all comparable can be secured is to obtain, not the temperature of the thermometer under radiation conditions, but as nearly as possible the temperature of the free air surrounding the thermometer.

We have seen that a relatively large amount of heat is required to change liquid water to water vapor. Evaporation is going on at all times, even when the air is saturated, although when saturation has

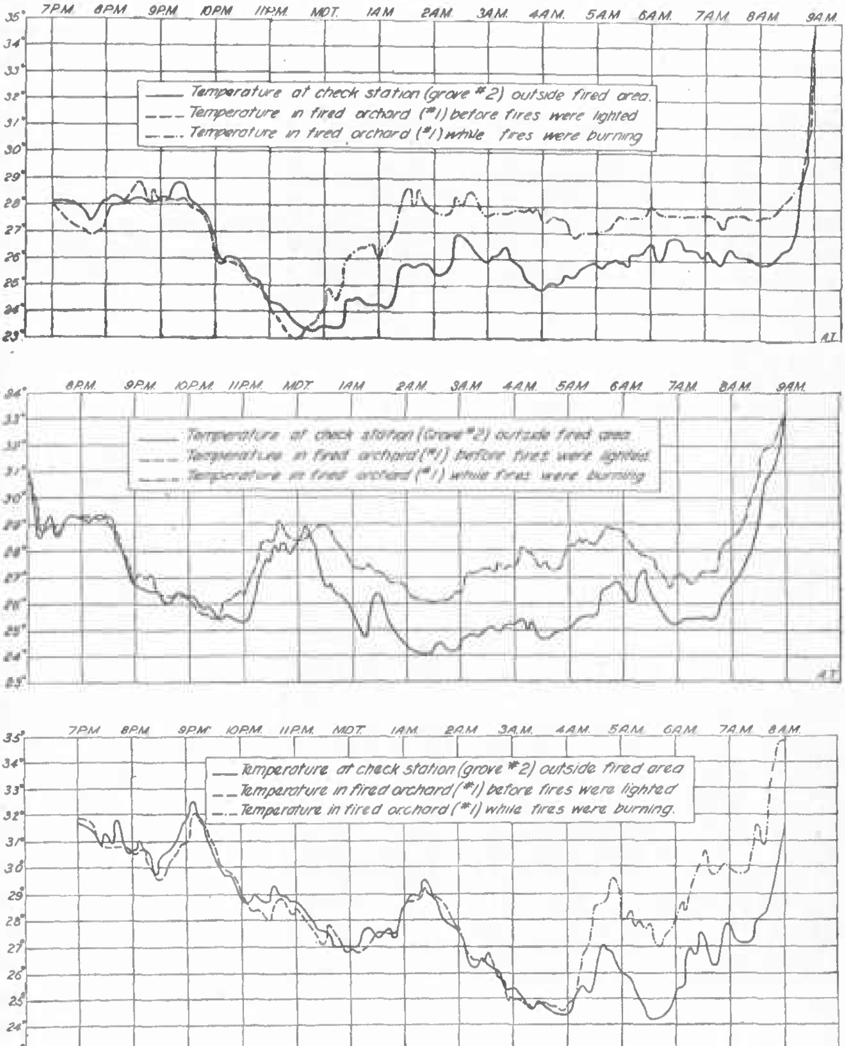


FIG. 17.—Continuous records of the air temperature inside standard instrument shelters in the two orange groves for which the comparative yields are given above. The grove at station C was not protected. The grove at station H was partially protected with coal heaters, set 50 to the acre. Station H was located in a row which contained no heaters and the temperature was probably somewhat higher in the rows containing heaters while firing was in progress. Note that the temperature fell as low as 23° for a short time, without any permanent injury to the fruit. As the weather had been cold for some time before these low temperatures occurred, however, the trees and fruit were considerably more resistant to cold than usual.

been reached, the condensation of vapor balances the evaporation. Evaporation also takes place directly from ice. When a thermometer is covered with a film of water or ice, or contains frost on the bulb,

the evaporation that is taking place absorbs heat from the thermometer and cools it to below the temperature of the air. The amount of cooling depends on the amount of moisture in the air and on the rate at which the air is moving past the thermometer.

It is plain that if a thermometer is to register the temperature of the air, it must be sheltered from the sky and from direct sunlight, and also must be exposed in such a way that moisture from any source is not likely to gather on it.

FIG. 18.—Standard type of instrument shelter used by the Weather Bureau. The shelter is always placed so that the door opens toward the north so that the sun can not shine directly on the instruments when the door is open.

Free circulation of the air is also an important requirement for a satisfactory thermometer exposure. If a shelter offers much obstruction to air circulation the air inside the shelter may cool at a slower or faster rate than the outside air and the thermometer in the shelter will then fail to indicate the true temperature of the outside air. It is essential, therefore, that a thermometer shelter allow as free a circulation of the air as possible without sacrificing the elements of protection from sunlight and liquid or frozen moisture. The standard Weather Bureau shelter has a double roof to prevent undue warming of the inside air by the sun's rays, and the bottom is as open as possible. The sides are louvred, the openings being as wide as possible without allowing the direct sunlight to reach the interior. (See fig. 18.)

All thermometers used in determining temperatures in orchards should be exposed with the foregoing principles in mind. A simple

but fairly satisfactory method of sheltering a thermometer which is used only at night is to place a large thin flat board horizontally directly above it. The thermometer should be placed close up under the board so as to cut off as much of the sky as possible.

In reading a thermometer on a cold night, care should be taken not to breathe directly on it. Whenever possible, an electric flash-light

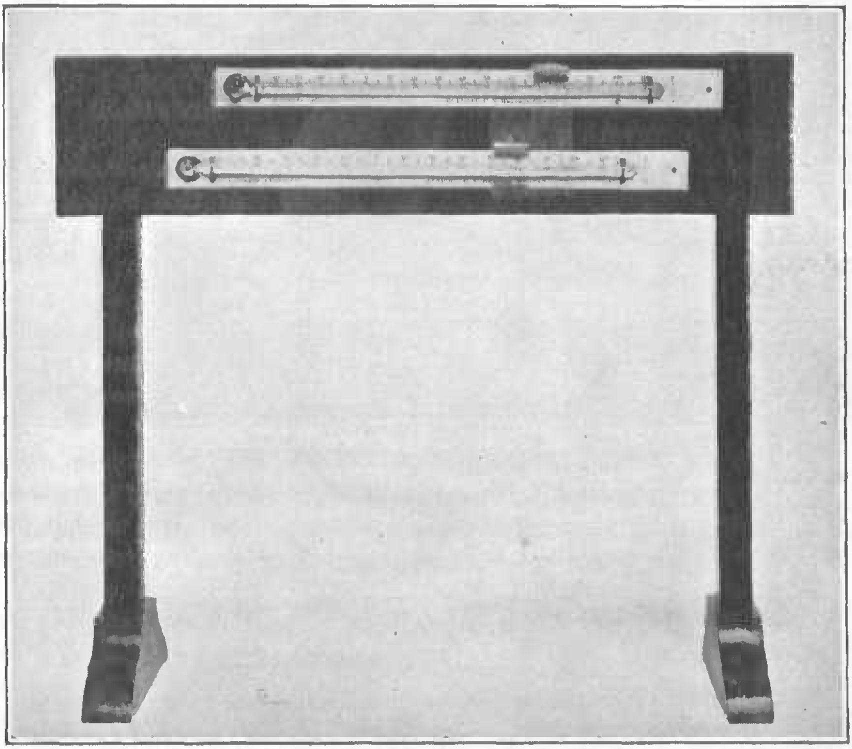


FIG. 19.—Types of thermometers used by the Weather Bureau to register the highest and lowest temperature.

should be used in making readings. When matches or candles are used to illuminate the thermometer, the temperature may be raised a degree or more before the reading can be made, which may in some cases results in loss of fruit through not lighting the heaters in time.

Every orchardist who has frost-fighting equipment should have at least one accurate dependable thermometer to be placed in the coldest part of the orchard, preferably one which will register the minimum temperature. (See fig. 19.) Cheaper thermometers can be scattered throughout the remainder of the orchard. These should be carefully compared with the standard thermometer at least once each year and inaccuracies noted. Those which are found to be in error more than one degree near the freezing point should be discarded. Cards showing the corrections to be applied at different points on the

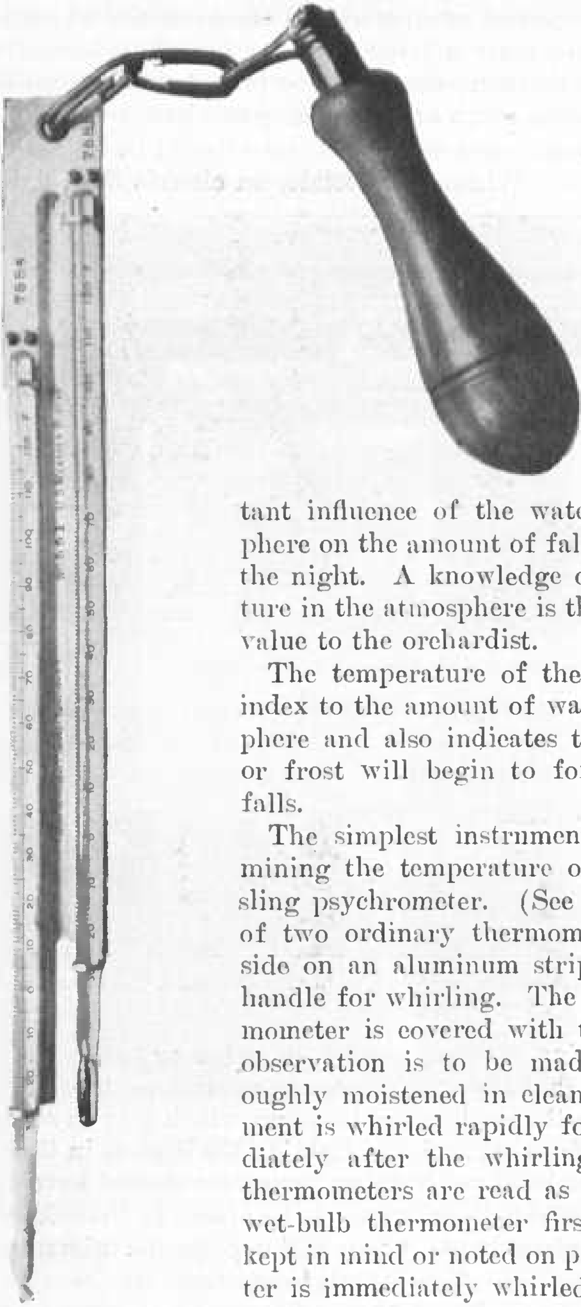


FIG. 20.—Sling psychrometer used to determine the amount of moisture in the atmosphere.

scale to make the readings agree with the standard should be attached alongside all thermometers which are not strictly accurate.

MEASUREMENT OF ATMOSPHERIC MOISTURE.

On an earlier page of this bulletin reference has been made to the important influence of the water vapor in the atmosphere on the amount of fall in temperature during the night. A knowledge of the amount of moisture in the atmosphere is therefore of considerable value to the orchardist.

The temperature of the dew point is a direct index to the amount of water vapor in the atmosphere and also indicates the point at which dew or frost will begin to form as the temperature falls.

The simplest instrument for accurately determining the temperature of the dew point is the sling psychrometer. (See fig. 20.) This consists of two ordinary thermometers mounted side by side on an aluminum strip and provided with a handle for whirling. The bulb of the lower thermometer is covered with thin muslin. When an observation is to be made, the muslin is thoroughly moistened in clean water and the instrument is whirled rapidly for a short time. Immediately after the whirling is discontinued both thermometers are read as quickly as possible, the wet-bulb thermometer first. These readings are kept in mind or noted on paper and the psychrometer is immediately whirled again and more readings are taken. This is repeated several times, until two readings of the wet-bulb thermometer agree closely or until the wet-bulb temperature begins to rise. In other words, it is desired to

obtain readings of the two thermometers after the wet-bulb thermometer has reached its maximum depression.

If the wet-bulb temperature falls to 32° F. and remains at that point, the whirling should be continued for some time later, even

FIG. 21.—Improved high-stack heaters in place in orange grove.

though two or three successive whirlings fail to cause it to read lower. When the water in the muslin begins to freeze, sufficient latent heat is liberated to keep the temperature at 32° until all the water on

FIG. 22.—Short-stack oil heaters in place in an orange grove.

the thermometer bulb is frozen. After this occurs, the evaporation from the ice may cause the wet-bulb thermometer to read below 32°.

After the final readings have been made the wet-bulb temperature is subtracted from the dry-bulb temperature and the temperature of

the dew point is found by referring to special tables, usually furnished with the psychrometer.

The psychrometer should be whirled and read in the shade.

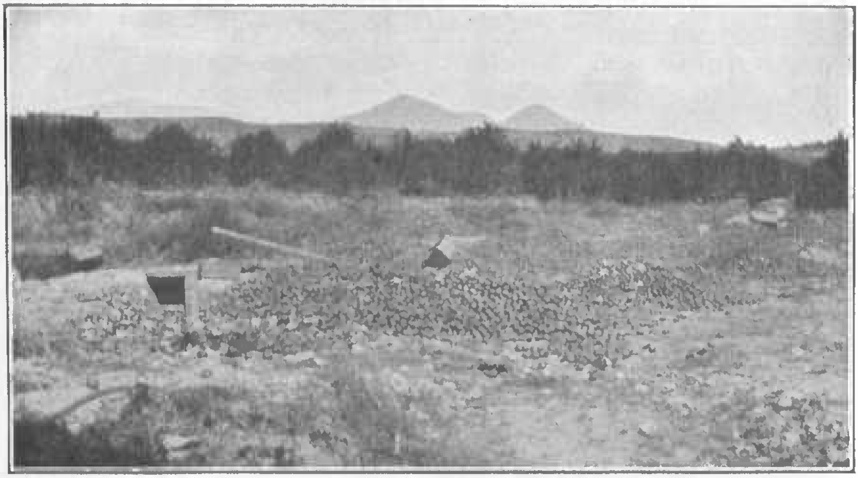


FIG. 23.—A corner of a frozen orange dump after a cold season. Thousands of dollars worth of otherwise perfect fruit a total loss through frost damage.

Considerable heat is required to evaporate water, and the heat removed from the bulb of the wet thermometer for this purpose causes its temperature to fall. The less moisture already in the atmosphere the more rapidly the evaporation goes on and the lower is the temperature of the wet bulb. When the atmosphere is saturated the readings of the dry and wet bulb thermometers are the same.

FIG. 24.—Frozen oranges dumped in lemon grove to be plowed under for fertilizer. Very little frozen fruit is used in this way, as most growers believe too much acid is added to the soil.

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